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Impact of Flour Particle Size and Starch Damage on Baking Properties of Wheat Flour Grown in Dry Climates: A Uzbekistan Case Study †

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Abstract: The impact of flour particle size and starch damage on the baking properties of wheat flour cultivated in dry climates, focusing on Uzbekistan, was investigated. Given the critical role of bread and flour products in Central Asian diets, understanding grain cultivation's influence on these products is imperative. Dry climates affect wheat quality, particularly its protein and glutenin content, influencing dough resistance and bread appearance. This study evaluated how flour particle size and starch damage affect baking properties using wheat flour grown in semi-arid regions, aiming to assist wheat growers in post-harvest irrigation decisions. Through a combination of chemical and physico-chemical methods, including particle size analysis, damaged starch measurement, and baking tests, this study elucidated the relationship between flour characteristics and baking performance. Results indicate that smaller flour particle sizes enhance dough-mixing properties, but may adversely affect crumb firmness. Furthermore, high levels of starch damage negatively impact flour quality and baking properties. Importantly, this study underscores the significance of understanding these factors in optimizing wheat cultivation and flour processing for improved bread quality in dry climates. Specifically, results show that for high-grade flour (Sardor), the control sample had a gluten content of 25.6%, with a drop number of 190 and a degree of starch damage of 26.9 units. Conversely, flour samples from locally grown soft wheat demonstrated higher starch damage, ranging from 3.4 to 3.9 units compared to imported samples. Additionally, regression analysis revealed significant coefficients for particle size and starch damage on the amount of wet gluten washed from these flour samples.

Keywords: wheat cultivation; bread quality; flour particle size; starch damage; baking properties; dry climate agriculture; protein content in wheat

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1. Introduction

Global trends emphasize the need for food production development, product diversification, and environmental cleanliness, especially in Central Asia, where bread and flour products are dietary staples. Understanding grain cultivation's impact on these products is crucial [1]. Flour quality, influenced by particle size and starch damage, is vital for the baking industry. Dry climates affect wheat and flour, increasing protein and gluten content and impacting dough resistance and bread appearance [2]. High-protein flour produces better-structured bread, highlighting climate's role in quality.

These flour properties are shaped not only by the milling process, but also by the environmental conditions under which wheat is grown. In regions like Uzbekistan, characterized by a dry, arid climate, the unique challenges of wheat cultivation—such as limited rainfall and high temperatures—lead to variations in kernel hardness, protein content, and starch structure, all of which influence flour behavior during baking [3].

The dry climate in Uzbekistan results in the production of harder wheat varieties that are more prone to starch damage during milling, which can increase water absorption, but disrupt dough's structure and handling properties [4]. Flour particle size is also affected by the milling process, and differences in particle size distribution can significantly alter dough rheology, gluten development, and bread quality [5]. Finer particles tend to increase water absorption and gluten development, while coarser particles may limit these processes, potentially resulting in a denser bread with a lower loaf volume [6].

This study examines the impact of flour particle size and starch damage on baking properties using wheat flour from semi-arid regions, aiming to assist wheat growers making post-harvest irrigation decisions [7]. Wheat is crucial for baking, and its chemical and physical properties determine baked product quality [8]. Flour particle size distribution and starch damage during milling affect flour's functional properties [9]. Modern baking technology reduces mixing time and increases productivity [10].

Wheat flour varies in particle size, affecting baked goods' structure and quality. Smaller particles lead to faster staling [11]. This study explores particle size and starch damage's impact on baking properties, the influence of dry climates on flour quality, and relationships between flour properties and baked goods. Objectives include investigating particle size effects on water absorption, starch damage, dough rheology, pasting properties, and assessing baking and sensory properties.

2. Literature Review

Flour particle size is key in wheat milling. A flow-through imaging system measures particle size, showing that hard and soft wheat produce different distributions in the break system, the first mill rolls. Understanding these distributions helps optimize the break system for better-sized particles, which is crucial for the first break when particles move to purification [12].

Endosperm sifting and granule size in flour depend on starch granules' surface area and shape. Small, polygonal granules pack tightly, decreasing sifting property, while large, oval granules increase it [13]. Starch damage that occurs during endosperm breakdown affects flour's physical and functional properties, such as water retention and pasting. High starch damage reduces water absorption, loaf volume, and crumb structure [14].

Researchers have advanced technology and improved raw materials' functional properties in bakery flour from arid-climate wheat. G.Z. Dzhakhangirova used fruit and vegetable powders to enhance bread quality and nutritional value [15]. K.S. Rakhmonov used Polish strains of yeast and fruit powders to improve bread quality by 16% [16]. I.M. Mamatov accelerated dough fermentation with electromagnetically activated water [17]. I.B. Isabaev used modified oils with high nutritional value and low trans fats [18]. S.S. Ravshanov studied the hydrothermal treatment of wheat to improve flour yield and quality [3]. J.D. Mirzaev examined small, damaged starch grains' impact on dough properties, finding higher damage in hard red spring wheat that affected water absorption and gas retention during baking. Soft white wheat has shown more variable particle size distribution [4]. Baking technology advancements make it crucial to understand flour characteristics, climate conditions, and their impact on performance and quality. Dry, hot climates lower grain moisture, compromising wheat quality [18]. Research on climate's effect on wheat flour baking properties is limited, leaving much to explore [19,20].

Flour particle size is crucial for food products, especially baked goods. Particle size distribution affects flour formation, often determined by ash content and extraction rate. Different milling systems produce various particle sizes, described by the Ribicoff index and the Pearson standard. Studies have shown that smaller particles lead to faster staling [21].

Damaged starch, mechanically or thermally altered during milling, affects dough and baked product properties, reducing dough's strength and stability by competing with gluten for water [22]. The relationship between damaged starch and bread quality varies across flour types and baking conditions [23].

Therefore, the relationship between damaged starch and wheat flour quality needs to be further examined, particularly in research in the area of bread quality in hot climates.

3. Methodology

A total of 22 wheat samples, including "Sardor" (Uzbekistan) and "Rozovskaja 7" (Russia), were collected from 2022 and 2023 harvest years across different regions to reflect diverse climates. The wheat samples used were of the hard red spring wheat variety. This study employed a combination of general, modern chemical, and physico-chemical methods. These included full factorial experimental methods, as outlined in the "Rules for the Organization and Implementation of the Technological Process in Bread-Making Enterprises". These methods were used to create regression equations, validate their adequacy, and graphically represent results. Analytical analysis methods were also utilized.

The particle size of flour was determined in accordance with GOST 27560-87 [24]. To assess the graininess of wheat flour, 50 g of medium-grade flour (samples RA-5 and RL-47) was analyzed using laboratory sifting equipment or manually according to the standard. The content of damaged starch was measured using the SDMatic instrument according to the amperometric method outlined in ISO 17715-2013, which allows for an objective evaluation [25].

The whiteness of flour was determined according to ISO 16624:2020 [26]. The quantity and quality of gluten in bakery wheat flour were assessed in line with ISO 21415-2:2015 [27]. The 'falling number', which is an indicator of the quality of wheat and rye grains, as well as the baking flour made from them, was measured following ISO 3093:2009 [28]. Baking tests were performed. A mixograph is dough testing equipment designed to measure the resistance of a dough to mixing and the extent of dough strength development during mixing. In the present study, a National Manufacturing Company's (Toledo, OH, USA) Farinograph was employed to measure water absorption and dough development time for the same samples of flour used in the mixograph test. The baking adaptation of the Rapid Visco Analyzer (Newport Scientific, Australia) was used to measure flour quality as affected by starch gelatinization when mixed with water and subjected to high temperature. Baking test methods used in the present study were mainly modified from previous studies by Ng (Todd) and Manthey. Alveograph tests were conducted using a Chopin Alveograph (model 982071, Paris, France). It measures the ability of a dough to resist the extension force as well as its extensibility.

The Alveoline software developed by the Chopin company (Paris, France) was used to receive, process, and store test results via an RS-232 serial port interface with the computer. Prior to alveograph tests, each sample was kneaded and rested for 20 min according to the standard ISO 5530-1:2013 [29]. Wheat flour quality and underlying gluten strength were characterized by the alveograph from certain samples from 2022 and 2023 harvests, including control samples as well as flour in different punch numbers and maximum overpressure. All these baking tests were conducted in the pilot processing laboratory possessed by the Department of Technology of Food Products in the Tashkent Institute of Chemical Technology, where the environmental conditions were well controlled, at about 23 °C and 50% relative humidity.

4. Results and Discussion

Small-sized and mechanically damaged starch grains in samples of high-grade and first-grade flour, including imported varieties of soft wheat grown in dry climates, were separated into fractions. Changes in their baking and technological properties were analysed, as presented in Table 1.

Table 1. The effect of a granulometric fraction content of less than 10 µm on the baking properties of flour samples in this study.

Flour Samples	Color Unit Indicator (SKIB-M Whiteness Meter Unit)	Gluten Content, %	Elasticity of Gluten (GDI Instrument Conditional Unit)	Moisture, %	Number of Drops (PCHP-7 Device Unit)	Degree of Starch Damage (CDMatic Device Unit)
High grade flour (Sardor)	53	25.6	83	13.1	190	26.9
	57	24.8	97	11.8	122	29.9
	54	27.5	74	11.6	196	23.4
First grade flour (Sardor)	50	26.7	85	13.5	186	26.6
	55	26.4	111	11.4	126	29.4
	50	29.7	72	11.5	190	23.1
High grade flour (Rozovskaja 7)	66	30.2	63	13.2	196	23.5
	66	28.4	65	11.2	184	19.8
	63	30.8	66	11.5	208	22.7
First grade flour (Rozovskaja 7)	55	32.4	71	13.6	214	22.7
	58	29.1	83	11.6	198	20.4
	56	33.6	75	11.6	221	23.3

The colour of each cell indicates sizes of flour fractions as follows: Control; Up to 10 µm; Above 10 µm.

Experiment results (Table 1) reveal that color unit indicators of all flour samples complied with the ISO 16624:2020 standard. However, it was observed that gluten content and its gluten deformation index (GDI) conditional unit indicators in flour samples from locally grown soft wheat did not meet GOST 27560-87 standards, whereas imported flour samples did. In the drop number analysis, according to GOST 27839-2013 [30], local flour samples were found to be unsuitable. Furthermore, when assessing the level of mechanical damage to starch in flour (ISO 17715-2013), local soft wheat flour samples showed 3.4 to 3.9 units higher damage compared to imported samples. This indicates that small-sized and mechanically damaged starch grains significantly impact the baking properties of flour made from local wheat grains.

Prior to experimentally studying the impact of granulometric fractional composition (less than 10 µm) and damaged starch isolated from baking-grade wheat flour, experiments were planned, and results were mathematically processed. This study focused on the effects of granulometric fractions smaller than 10 µm and the extent of starch damage on the baking and technological properties of flour samples. This included evaluating the amount of wet gluten and its elasticity.

Results demonstrate the significant influence of flour particle size on the baking properties of high-grade and first-grade wheat flours from *Sardor* and *Rozovskaja 7*. Finer particles (below 10 µm) in *Sardor* flour resulted in increased gluten elasticity (up to 111 units) and higher starch damage (up to 29.9), indicating greater water absorption and gluten development, but also a risk of dough instability. Conversely, coarser particles (above 10 µm) in *Rozovskaja 7* flours led to higher gluten content (up to 33.6%) and greater dough resilience, as evidenced by a higher number of drops (up to 221), indicating stronger dough performance. Moisture content was generally higher in samples with finer particle sizes, while coarser fractions contributed to improved dough strength and gluten content. Overall, finer particles enhanced gluten elasticity, whereas coarser particles favored dough structure and stability. These results suggest that controlling flour particle size during milling is critical for optimizing baking quality, particularly for balancing elasticity and dough strength.

Results presented in Table 2 reveal the influence of granulometric fractions smaller than 10 µm and starch damage on the amount of wet gluten extracted from flour samples. Four experiments were conducted with varying levels of granulometric fractions and starch damage. The amount of wet gluten washed from the flour samples (y1, y2, and y3) ranged from 24.4% to 27.7%. Experiment 2, with higher granulometric fractions (x1 = 7.7) and moderate starch damage (x2 = 18.2), produced the highest wet gluten content (27.7%). Conversely, Experiment 1, with smaller particle sizes (x1 = 4.4), but similar starch damage, yielded the lowest gluten content (24.4%). This indicates that coarser fractions and moderate starch damage improve wet gluten yield, while finer fractions reduce it. These results demonstrate the importance of controlling particle size and starch damage to optimize gluten extraction, contributing to enhanced dough strength and improved baking performance.

Table 2. Experimental matrix to determine the influence of the amount of granulometric fractions with a size smaller than 10 µm and the degree of starch damage (by superior grade) on the amount of wet gluten washed from flour samples.

Experiment No.	Influencing Factors			Range of Values of Influencing Factors (Min and Max)		Results of Experiments		
	z0	z1	z2	x1	x2	y1	y2	y3
1	1	−1	−1	4.4	18.2	24.8	24.6	24.4
2	1	1	−1	7.7	18.2	27.5	27.3	27.7
3	1	−1	1	4.4	31.1	26.2	26.60	26.8
4	1	1	1	7.7	31.1	25.7	25.5	25.3

In this case, the regression equation is as follows:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 \quad (1)$$

Regression coefficients were calculated using the following formula:

$$b_0 = \frac{\sum_{i=1}^{N} y_i}{N} \quad (2)$$

Results of calculating regression coefficients are presented in Table 3.

Table 3. Results of regression coefficient calculations.

Coefficients	b_0	b_1	b_2	b_{11}	b_{22}	b_{12}	b_{23}
Values	26.01	−0.46	−0.93	0	0	0.0083	0

The calculated value of the Student's criterion was determined by following Equation (3):

$$|b_j| = m_{cr} \cdot C_{coef} \quad (3)$$

$|b_j| <= m_{cr} \cdot C_{coef} = 2.92 \cdot 0.062 = 0.18$ when comparing the obtained value of 0.18 with the coefficients of the regression equation b_{12}, all coefficients are extreme in absolute magnitude, and $|b_j|$ can be seen to be large. Thus, this coefficient was removed from the regression equation, and the final regression equation is as follows:

$$y = 26.01 - 0.46 \cdot x_1 - 0.98 \cdot x_2 \quad (4)$$

According to the obtained equation, a graph of the effect of the amount of granulometric fractions smaller than 10 µm and the degree of starch damage on the amount of wet gluten washed from flour samples was plotted in the MathCAD program (Figure 1).

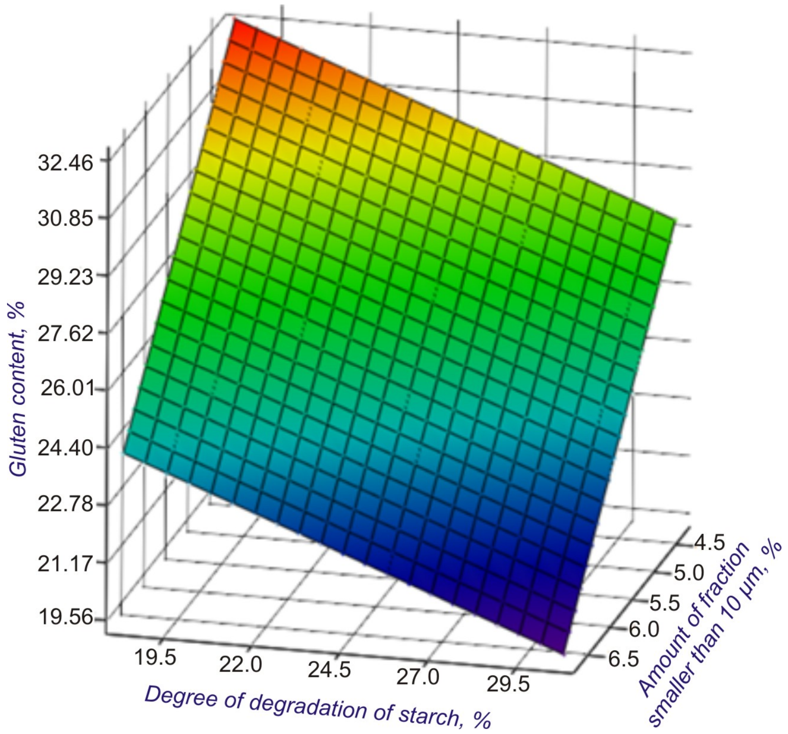

Figure 1. Influence of the amount of granulometric fractions smaller than 10 µm and the level of starch damage on the amount of wet gluten washed from flour samples.

Increased flour particle size produced dough with better mixing properties, easier handling, and better tolerance during dividing and moulding. Loaf volume steadily increased with decreasing mean flour particle size up to a particle size of about 46 µm. However, further decreases in the particle size resulted in a decrease in loaf volume. Loaf volume was at its maximum value at a mean flour particle size of 46 µm, which is considered the optimum particle size for bread baking. However, crumb firmness increased with a decrease in the mean flour particle size, which means a particle size much smaller than 46 µm is not desirable for bread baking. Loaf volume and crumb softness were used as response variables for the establishment of the empirical relationship between flour particle size and baking properties using response surface methods. Crumb softness decreased with a decrease in particle size and became steady at about 150 µm. Such an increase in crumb firmness with decreasing particle size might be attributed to a decrease in bread porosity. R-squared values for the empirical relationships established were high (greater than 0.9), indicating those equations had good predictive capabilities. Quadratic models were selected for both loaf volume and crumb softness, and the significance of model terms was checked. Such terms included the first order terms of flour particle size, gluten content, and damaged starch level, and the interaction term between particle size and damaged starch. Results showed that flour particle size and damaged starch had significant impacts on loaf volume and crumb softness. However, gluten content did not show a significant effect on those responses. This finding was contradictory to some reports in the literature, and it may be due to the fact that the gluten contents of flour samples used in this study were in the typical range and differences were not large enough to express significance.

5. Conclusions

In conclusion, these research results highlight the crucial relationship between flour properties, climate conditions, and their impact on baked goods quality in Central Asia. By examining the effects of flour particle size and starch damage on baking properties, particularly in wheat grown in arid climates, this paper provides insights into optimizing wheat cultivation and processing techniques. Quantitative analysis revealed that an optimal flour particle size of about 46 µm resulted in better baking properties, increasing loaf volume and maintaining crumb softness. Deviations from this size reduced baking quality, emphasizing the importance of particle size control. Qualitative assessments showed that damaged starch significantly influences dough strength and stability, affecting bread quality. Mechanically or thermally damaged starch grains negatively impacted water absorption, dough development, and bread texture, highlighting the need for careful milling practices. Additionally, this research demonstrated how environmental factors like temperature and humidity affect wheat quality and flour properties. Analysis showed that dry region climates impact wheat development, flour composition, and baking outcomes. Overall, this study's results advance food production sustainability to ensure high quality, nutritious wheat-based food products. It bridges the gap between theory and practice, aiding decision-making in agriculture and food processing, benefiting producers and consumers.

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