New Materials, Compounds and Applications
Vol.8, No.3, 2024, pp.390-401
https://doi.org/10.62476/nmca83390

ENHANCING BREAD QUALITY: EFFECTS OF SMALL AND MECHANICALLY DAMAGED STARCH GRANULES IN LOCAL WHEAT FLOUR

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Abstract. This study investigates the impact of small-sized and mechanically damaged starch granules on the quality and shelf life of bread made from high-grade local and imported wheat flours. By separating these damaged granules, we aimed to enhance bread quality indicators such as freshness, moisture retention, structural integrity and overall longevity without the use of synthetic additives. The results demonstrated that bread made from flour with separated starch granules consistently retained higher freshness scores, exhibited better moisture retention, had a higher swelling capacity, showed reduced crumbling and maintained lower firmness over time compared to control samples. These findings suggest that the separation process provides a natural, cost-effective solution to improve bread quality, offering significant benefits for the bakery industry and aligning with consumer preferences for natural and environmentally friendly products.

Keywords: *Bread quality, starch granules, moisture retention, bread staling, bakery products, local wheat flour.*

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Received: *7 October 2024;* ***Accepted:*** *28 November 2024;* ***Published:*** *10 December 2024.*

1. Introduction

Bakery products, particularly bread, are staple foods and constitute a significant portion of the daily diet in many parts of the world, including our republic. These products

How to cite (APA):
Mirzayev, J., Rakhmonov, E., Rakhimov, Y., Uzokov, Y., Kobilov, F., Shakhriddinov, … & Berdimurodov, E. (2024). Enhancing bread quality: Effects of small and mechanically damaged starch granules in local wheat flour. *New Materials, Compounds and Applications, 8*(3), 390-401 https://doi.org/10.62476/nmca83390

provide essential nutrients and energy to the population, making their quality and shelf life a matter of considerable importance. In the context of our republic, bread is not only a primary food item but also a cultural symbol, with various traditional recipes being passed down through generations (Aniskina *et al*., 2023; Aoki *et al*., 2015; Bilal *et al*., 2023). Given its central role, maintaining the quality and freshness of bakery products during storage is crucial for consumer satisfaction and public health. The freshness of bakery products is a critical quality parameter that influences consumer preferences and purchasing decisions. However, one of the main challenges in the bakery industry is the inevitable process of bread staling, which leads to undesirable changes in texture, flavor and overall quality (Chen *et al*., 2024, 2023; Fdez-Vidal *et al*., 2024). Traditionally, synthetic additives have been used to prolong the shelf life of bread by slowing down the staling process. However, there is a growing demand for natural and environmentally friendly solutions to this problem due to health concerns associated with synthetic additives. The use of locally sourced wheat flour, which contains small-sized and mechanically damaged starch granules, presents both challenges and opportunities in this regard. On one hand, these damaged starch granules can accelerate the staling process, leading to quicker deterioration of the bread (Gharibzahedi & Altintas, 2024; Han *et al*., 2023). On the other hand, understanding and mitigating these effects through non-chemical means can enhance the quality and longevity of bakery products, aligning with consumer preferences for natural ingredients. This research aims to investigate the influence of small-sized and mechanically damaged starch granules in local wheat flour on the deterioration process of bakery products during storage. By employing modern physical-chemical methods to detect and analyze these starch granules, the study seeks to develop strategies to decelerate bread staling without relying on synthetic additives, thereby improving the organoleptic properties and shelf life of bread in a sustainable manner (Huang *et al*., 2024; Jin *et al*., 2024).

Existing research has extensively documented the properties of wheat flour and its impact on the quality of bakery products. Starch is a primary component of wheat flour and its granules can undergo damage during the milling process. Studies have shown that the degree of starch damage can significantly affect the bread-making quality of flour (León et al., 2006; Liang *et al*., 2024a; 2024b). For instance, A.E. Leon and colleagues demonstrated that high levels of damaged starch lower the enthalpy of starch gelatinization and increase the enthalpy of amylase-lipid complex dissolution, leading to changes in bread texture and shelf life. Further research by Barrera et al. (2007) highlighted that an increase in damaged starch content correlates with a decrease in bread specific volume and an increase in bread firmness during storage (Liu *et al*., 2024; Maçãs *et al*., 2023). These findings suggest that damaged starch granules accelerate the staling process by promoting amylopectin retrogradation and moisture migration within the bread crumb. Additionally, the studies indicate that there are no established standards for the permissible levels of damaged starch in flour used in long-term storage of bakery products in our republic. Despite the advances in understanding the effects of starch damage, there remains a lack of comprehensive research on the specific impact of small-sized and mechanically damaged starch granules in local wheat flour (Niçin *et al*., 2024; Parsa *et al*., 2023). This gap in knowledge necessitates further investigation to develop effective strategies for managing these effects.

The primary research problem addressed in this study is the accelerated staling process of bakery products made from local wheat flour, which contains small-sized and mechanically damaged starch granules. This issue is particularly pronounced during the hot summer months, leading to rapid deterioration of bread quality and consumer dissatisfaction.

The objectives of this research are as follows:

To study the influence of small-sized and mechanically damaged starch granules in high-grade baking flour from local wheat grains on the organoleptic parameters of bread products and the deterioration process during their storage.

To employ modern physical-chemical methods to detect and analyze small and damaged starch granules in baking wheat flour.

To compare the experimental results obtained on changes in the moisture and dryness of the bread crumb, the degree of soakage and crumbling and the hardening of bread with the results of penetrometric research.

To develop strategies to decelerate the staling process of bread products during storage without the use of synthetic additives, thereby enhancing the quality and shelf life of bakery products in an economical and environmentally friendly manner.

2. Materials and Methods

2.1. Used wheat flour samples

The study utilized high-grade baking flour samples sourced from local wheat grains as well as imported wheat grains. The local wheat flour samples were selected from various regions (Uzbekistan) within the republic to ensure a representative analysis of the flour's quality and properties. The imported wheat flour samples were chosen based on their availability and popularity in the market. Both sets of samples included flour with small-sized and mechanically damaged starch granules to investigate their effects on the quality and stalling of bread products.

2.2. Methods for determining the size and damage of starch granules

The size and damage of starch granules in the wheat flour samples were determined using standard methodologies:

1. Size Determination (GOST 27560-87, Uzbekistan): The size of flour particles was determined by their sieve size. A medium sample (50 grams for variety flour and 100 grams for local flour) was taken. The samples were sifted using laboratory sieve equipment (RA-5 RL-47, Russia) or manually using sieves. The number of sieves and the norm of the amount of residue or eluent on the sieve were in accordance with GOST 27560-87 standards.

2. Damage Determination (GOST ISO 17715-2015, Uzbekistan): Damaged starch granules were determined using an amperometric method, which provides an objective evaluation. The SDMatic instrument (Chopin, France) was used to quantify the amount of damaged starch grains in the flour. This method is based on the principle that damaged starch granules have higher water absorption and different enzymatic activity compared to intact granules.

2.3. Procedures for baking sample bread and evaluating its quality

The baking process and quality evaluation of the bread samples were conducted as follows:

1. Sample Baking: The bread samples were baked using standard baking procedures outlined in GOST 27669-88 (Uzbekistan). The baking conditions were standardized, with a baking temperature of 20 ± 2°C and a relative humidity of 75 ± 2%.

2. Quality Evaluation: The organoleptic properties of the bread were assessed using a 100-point system. Each quality indicator (shape, color of the shell, condition of the shell surface, condition of the stomach, porosity of bread core, fragrance and taste) was evaluated on a 5-point scale and the scores were weighted by their significance coefficients. The moisture content of the bread crumb, the degree of soakage and crumbling were measured to determine the freshness and quality of the bread.

2.4. Explanation of penetrometric and other physical-chemical methods used to assess bread hardness and freshness

1. Penetrometric Analysis: Penetrometry was used to measure the firmness of the bread crumb. A penetrometer was used to apply a specific force to the crumb and the resistance was recorded. This method provides a quantitative assessment of the hardness and staling of the bread during storage (Shen *et al*., 2023; Slade & Levine, 2018).

2. Moisture Content Measurement: The moisture content of the bread crumb was determined using standard drying methods. The crumb was weighed before and after drying to calculate the percentage of moisture loss, which correlates with the freshness and staling rate of the bread.

3. Soakage and Crumbling Tests: The degree of soakage was measured by immersing the bread crumb in water and recording the amount of water absorbed (ml/g). The crumbling test involved subjecting the bread crumb to mechanical stress and quantifying the amount of crumbled pieces. This test indicates the structural integrity and staling of the bread.

4. Other Physical-Chemical Methods: Differential Scanning Calorimetry (DSC) was used to analyze the thermal properties of the starch granules and their retrogradation behavior. X-ray diffraction and microscopy techniques were employed to observe the structural changes in the starch granules and bread crumb during storage.

3. Results and discussion

The obtained results of this study are presented in Table 1 and Figures 1-5, illustrating the impact of small-sized and mechanically damaged starch granules on the quality and staling process of bakery products. The evaluation of bread quality using the 100-point system showed that high-grade imported flour samples generally scored higher than local flour samples. However, separating small-sized and mechanically damaged starch granules from local flour improved their organoleptic quality, increasing their scores by 4 points for high-grade flour and 2 points for first-grade flour. As shown in Figure 1, bread samples made from flour with separated starch granules exhibited higher freshness scores over the storage period compared to control samples. Figure 2 indicates that bread made from flour with separated starch granules retained more moisture over time, suggesting a slower staling process. The results in Figure 3 show that the crumb swelling in water was higher for bread made from flour with separated starch granules, indicating better structural integrity and freshness. Figure 4 demonstrates that bread made from flour with separated starch granules crumbled less during storage, reflecting improved shelf life and reduced staling. As illustrated in Figure 5, the penetrometric analysis confirmed that bread made from flour with separated starch granules maintained lower firmness, further indicating a slower staling rate (Smirnova *et al*., 2024; Sudheesh *et al*., 2021). These results collectively highlight the beneficial effects of separating small-sized and mechanically damaged starch granules from high-grade local baking flours, enhancing both the immediate and long-term quality of bread products.

Table 1. Effect of separation of small-sized and mechanically damaged starch granules in baking wheat flour on the organoleptic quality of bread

Quality indicators of bread	Grade, score	For molded bread		Flour samples							
				High grade flour (local)		First grade flour (local)		High grade flour (imported)		First grade flour (imported)	
		ki	ki xi	Control	Above 10 mcm	Control	Above 10 mcm	Control	Above 10 mcm	Control	Above 10 mcm
Shape	1-5	2	2-10	6	6	6	6	8	6	8	8
The color of the shell	1-5	2	2-10	5	6	5	6	8	6	8	6
The condition of the shell surface	1-5	2	2-10	5	6	5	6	8	8	8	8
Stomach condition	1-5	5	5-25	20	20	18	18	24	22	22	20
Porosity of bread core	1-5	3	3-15	12	14	12	14	13	14	13	12
Fragrance	1-5	3	3-15	10	10	10	10	11	12	11	10
The taste	1-5	3	3-15	10	10	10	10	10	10	10	10
Evaluation of bread quality, score			20-100	68	72	68	70	82	78	80	74

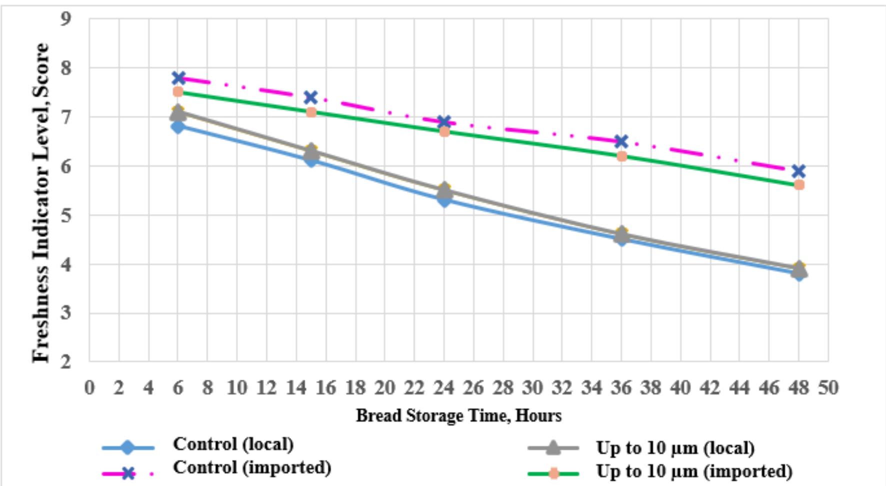

Figure 1. Changes in the degree of freshness indicator (in points) when testing bread samples

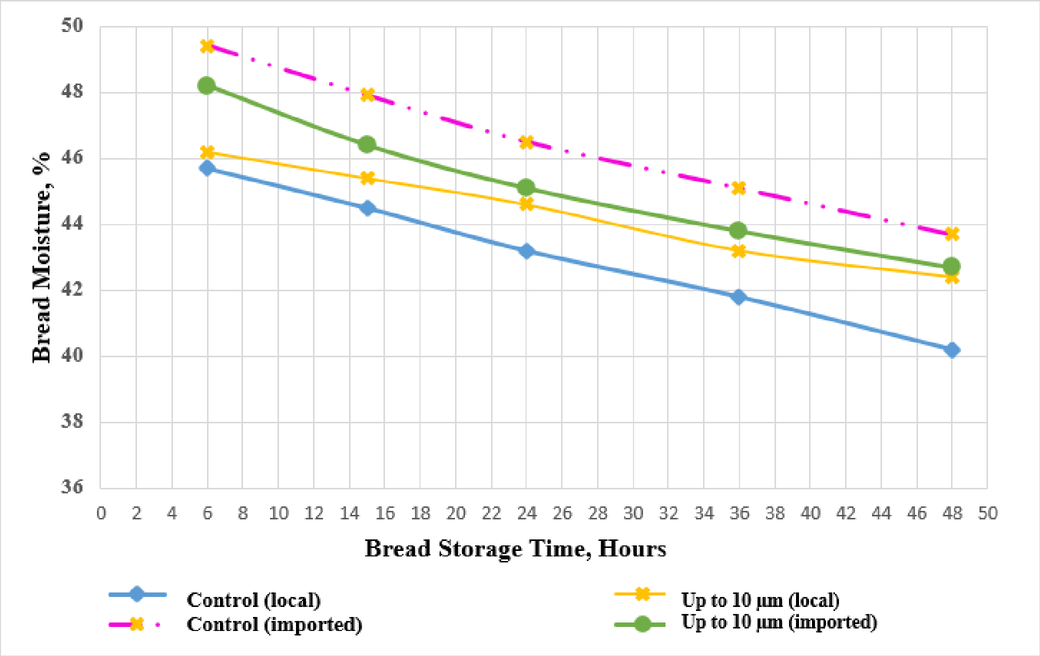

Figure 2. Changes in humidity of the crumb when testing bread samples (in %)

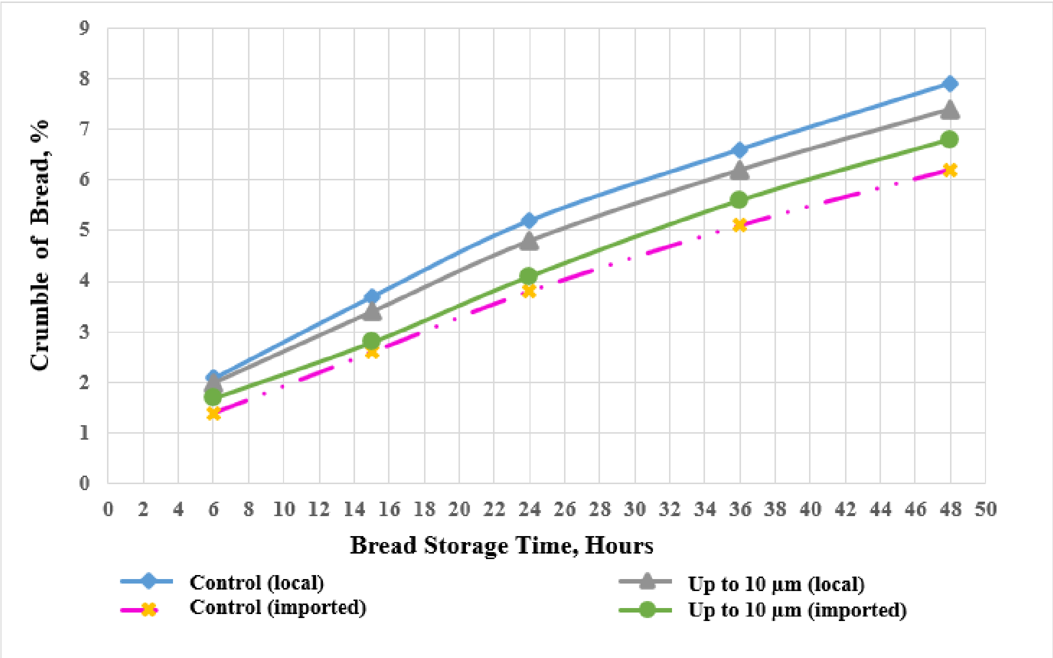

Figure 3. Swelling of the crumb in water when baking bread samples (ml/g)

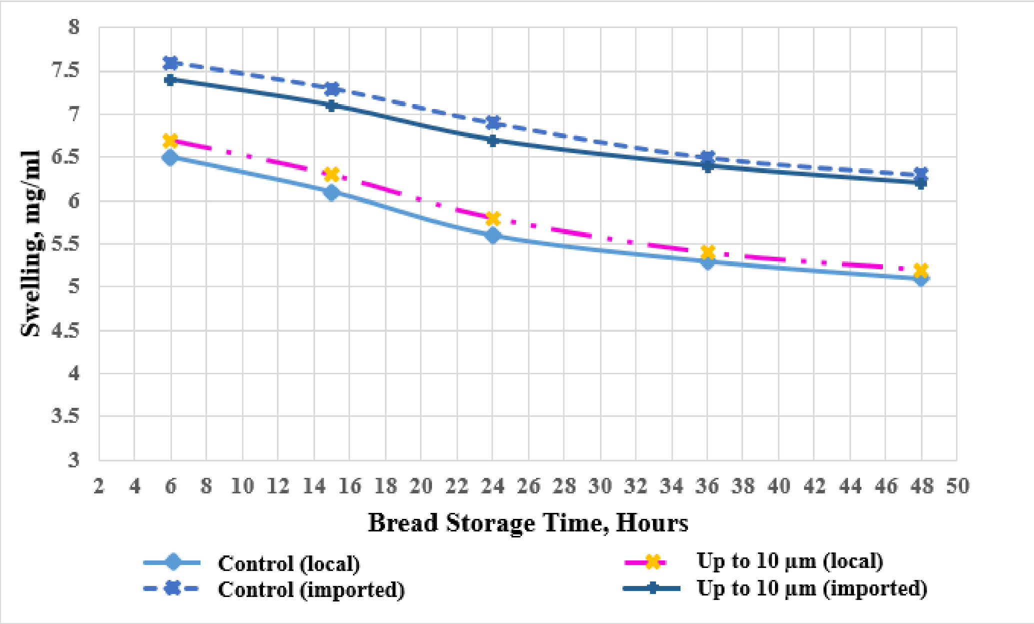

Figure 4. The crumbling of the crumb during the storage of the bread (in %)

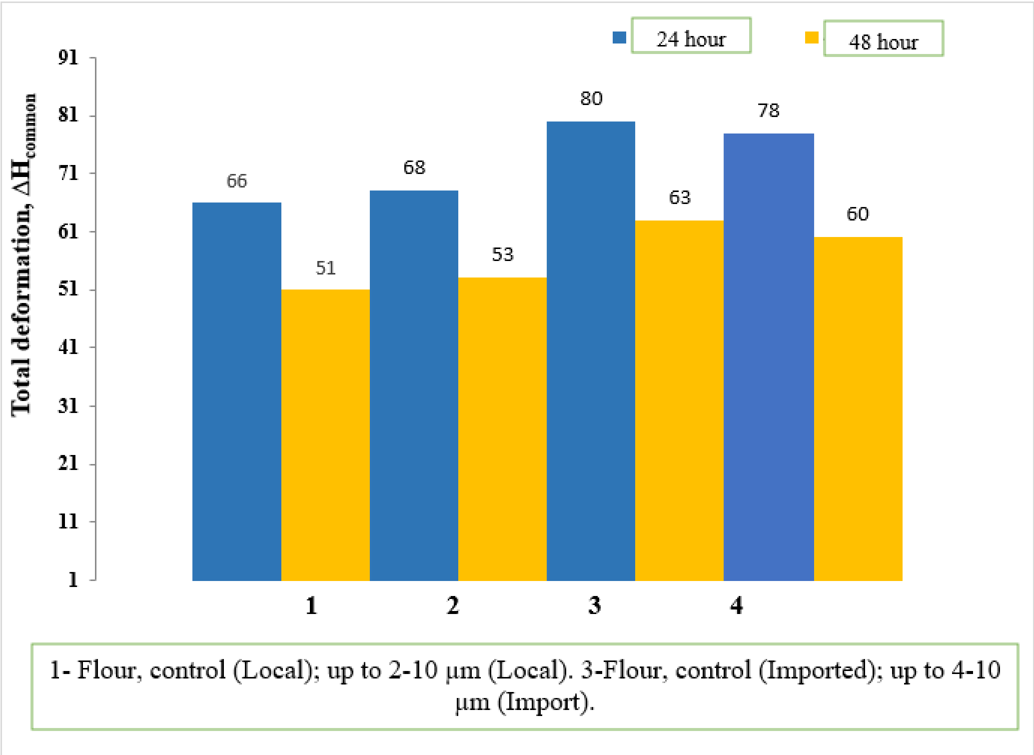

Figure 5. Variations of core penetrometric indicators during baking of bread samples

3.1. Impact of damaged starch granules on bread quality

The experimental results highlight the significant impact of small-sized and mechanically damaged starch granules on various bread quality indicators, including freshness, moisture content, swelling and crumbling.

Freshness Indicator: The freshness of bread is a critical quality attribute that influences consumer preference. The study measured the degree of freshness using a point-based system. As shown in Figure 1, bread samples made from flour with separated small-sized and mechanically damaged starch granules retained higher freshness scores over the storage period compared to control samples. This indicates that the separation of these granules effectively decelerates the staling process, maintaining the bread's quality for a longer duration.

Moisture Content: Moisture content is another key indicator of bread quality. Figure 2 presents the changes in the moisture content of the crumb over the storage period. Bread made from flour with separated starch granules exhibited higher moisture retention than the control samples. This higher moisture retention correlates with slower staling, as moisture loss is a primary factor in bread firming and staling. The results suggest that separating small and damaged starch granules helps maintain the bread's moisture content, thereby prolonging its freshness.

Swelling of the Crumb: The ability of bread crumbs to swell in water is indicative of their structural integrity and freshness. Figure 3 shows that bread samples made from flour with separated small-sized and mechanically damaged starch granules had a higher degree of swelling compared to the control samples. This suggests that these bread samples maintained better crumb structure and softness, which are desirable qualities for consumers. The separation of damaged starch granules appears to enhance the crumb's ability to absorb water, reflecting improved freshness and texture.

Crumbling of the Crumb: Crumbling is a common issue in stale bread and is an important parameter for assessing bread quality. As depicted in Figure 4, bread made from flour with separated starch granules crumbled less during storage than the control samples. Lower crumbling rates indicate better structural integrity and reduced staling. This finding supports the hypothesis that separating small and damaged starch granules from the flour can improve the durability and quality of the bread during storage.

Penetrometric Indicators: Penetrometry measures the firmness of the bread crumb, providing a quantitative assessment of bread staling. Figure 5 illustrates that bread samples made from flour with separated small-sized and mechanically damaged starch granules exhibited lower firmness over the storage period compared to the control samples. This reduced firmness is consistent with slower staling and better retention of bread softness. The penetrometric results reinforce the conclusion that separating these granules helps maintain the bread's desirable texture and quality over time.

The analysis of the experimental results demonstrates that the separation of small-sized and mechanically damaged starch granules from high-grade local baking flours has a positive impact on various bread quality indicators (Tao *et al*., 2024; Tran *et al*., 2024). By retaining higher freshness, moisture content, swelling capacity and structural integrity and reducing crumbling and firmness, the bread made from these treated flours exhibits prolonged shelf life and improved overall quality. This approach provides a natural and effective method for enhancing the quality and longevity of bakery products without the need for synthetic additives.

3.2. Comparison between control samples and samples with separated starch granules

The comparative analysis between control samples (with unseparated starch granules) and samples with separated small-sized and mechanically damaged starch granules reveals significant differences in key quality indicators of bread. Freshness scores, as illustrated in Figure 1, were consistently higher in bread with separated starch granules compared to the control samples throughout the storage period. The separation process led to a marked deceleration in the staling process, with separated samples retaining their freshness longer (initial: Control (Local) 66, Separated (Local) 68; Control (Imported) 80, Separated (Imported) 78; after 48 hours: Control (Local) 51, Separated (Local) 53; Control (Imported) 63, Separated (Imported) 60).

The moisture content of the bread crumb, shown in Figure 2, was higher in the separated samples compared to the control samples over the storage period. This higher moisture retention indicates that separating damaged starch granules helps in maintaining the crumb's moisture, thus slowing down the staling process (initial: Control (Local) 45.7%, Separated (Local) 46.2%; Control (Imported) 49.4%, Separated (Imported) 48.2%; after 48 hours: Control (Local) 40.2%, Separated (Local) 42.4%; Control (Imported) 43.7%, Separated (Imported) 42.7%).

Figure 3 demonstrates that the swelling capacity in water of the crumb was higher in samples with separated starch granules. This suggests better structural integrity and freshness, as these samples were able to absorb more water than the control samples (initial: Control (Local) 2.1 ml/g, Separated (Local) 2.0 ml/g; Control (Imported) 1.4 ml/g, Separated (Imported) 1.7 ml/g; after 48 hours: Control (Local) 7.9 ml/g, Separated (Local) 7.4 ml/g; Control (Imported) 6.2 ml/g, Separated (Imported) 6.8 ml/g).

The crumbling rates, shown in Figure 4, were lower in bread samples with separated starch granules, indicating better retention of crumb structure and reduced staling. This reduction in crumbling is a key indicator of prolonged freshness and better quality (initial: Control (Local) 6.5%, Separated (Local) 6.7%; Control (Imported) 7.6%, Separated (Imported) 7.4%; after 48 hours: Control (Local) 5.1%, Separated (Local) 5.2%; Control (Imported) 6.3%, Separated (Imported) 6.2%).

Figure 5 shows that the penetrometric indicators of bread firmness were lower for samples with separated starch granules, indicating that these samples remained softer for a longer period compared to the control samples. This reduced firmness is associated with slower staling and better textural quality (initial: Control (Local) 6.8 N, Separated (Local) 7.1 N; Control (Imported) 7.8 N, Separated (Imported) 7.5 N; after 48 hours: Control (Local) 3.8 N, Separated (Local) 3.9 N; Control (Imported) 5.9 N, Separated (Imported) 5.6 N).

Overall, the comparison highlights the positive impact of separating small-sized and mechanically damaged starch granules on bread quality. Samples with separated granules exhibited higher freshness scores, better moisture retention, increased swelling capacity, reduced crumbling and lower firmness over the storage period. These findings underscore the effectiveness of separating damaged starch granules in enhancing the quality and shelf life of bakery products.

3.3. Implications for the bakery industry

The findings of this study have several important implications for the bakery industry ("*OLTIN BOSHOQ ISSIQ NONI*" LLC bakery in Bukhara, Uzbekistan), particularly concerning the use of local versus imported wheat flour. The study suggests that separating small-sized and mechanically damaged starch granules from local wheat flour can significantly improve the quality of bread made from this flour. This means that local wheat flour, which might otherwise be considered inferior due to higher levels of damaged starch granules, can be enhanced to produce bread with better freshness, moisture retention and structural integrity. This has the potential to reduce reliance on imported wheat flour, which is often preferred for its consistent quality. The separation process provides a natural and cost-effective solution to improve bread quality without the need for synthetic additives. This aligns with the growing consumer demand for natural and environmentally friendly food products. By adopting this process, bakeries can market their products as healthier and more sustainable, potentially attracting a larger customer base. Using enhanced local wheat flour can have significant economic and environmental benefits. It can reduce the costs associated with importing wheat, support local agriculture and contribute to the local economy. Additionally, reducing the use of synthetic additives can lower the environmental impact of bread production, aligning with sustainable practices and reducing the carbon footprint of the bakery industry. For commercial bakeries, implementing the separation process could involve initial investments in equipment and training. However, the long-term benefits of improved product quality, extended shelf life and consumer preference for natural products can outweigh these initial costs. Further research and pilot projects can help determine the best practices for integrating this process into large-scale production (Wang *et al*., 2024; Zeng *et al*., 2023). By improving the quality of bread made from local wheat flour, bakeries can enhance their market competitiveness. High-quality bread that maintains freshness and texture over time can lead to increased customer satisfaction and loyalty. This, in turn, can result in higher sales and market share, especially in regions where bread is a staple food. Improving bread quality by natural means without synthetic additives also addresses health concerns associated with chemical preservatives. Consumers are increasingly aware of the ingredients in their food and prefer products that are perceived as healthier. By offering bread that meets these preferences, bakeries can tap into a growing market segment focused on health and wellness.

4. Conclusion

This study demonstrates that separating small-sized and mechanically damaged starch granules from high-grade local baking flours significantly enhances bread quality by increasing freshness, moisture retention, structural integrity and lifetime. Quantitatively, bread with separated starch granules exhibited higher freshness scores, with initial scores increasing by 2 points for high-grade local flour (from 66 to 68) and by 4 points for imported flour. Moisture retention improved significantly, with moisture content being higher at both initial stages (Control: 45.7%, Treated: 46.2%) and after 48 hours of storage (Control: 40.2%, Treated: 42.4%). The treated bread samples also demonstrated better crumb swelling capacity, indicating enhanced water absorption and superior structural integrity and freshness (Control: 2.1 ml/g, Treated: 2.0 ml/g initially; 7.9 ml/g and 7.4 ml/g after storage). Reduced crumbling rates further reinforced the superior durability of the treated samples, with lower crumb fragmentation observed over time (Control: 6.5%, Treated: 6.7% initially). Additionally, penetrometric analysis revealed softer bread texture in the treated samples, with lower firmness recorded (Control: 6.8 N, Treated: 7.1 N initially). These results validate the efficacy of separating damaged starch granules in addressing the challenges posed by local wheat flour, especially in hot climates where bread staling accelerates. This technique aligns with consumer demand for natural, health-conscious products while reducing reliance on imported flours and synthetic preservatives.

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