ANALYSIS OF THE EFFECT OF MECHANICALLY DAMAGED STARCH GRANULES IN FLOUR ON THE PROPERTIES OF BREAD WHEAT FLOUR

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https://doi.org/10.5281/zenodo.20135267

Abstract. Mechanical damage of starch granules during wheat milling significantly influences the technological and functional properties of bread wheat flour. This study investigates the effect of mechanically damaged starch on water absorption, dough rheology, fermentation behavior, and bread quality characteristics. The results showed that moderate starch damage improved dough hydration, enhanced yeast activity, increased loaf volume, and produced softer bread crumb with better moisture retention. Structural disruption of starch granules increased enzymatic susceptibility and facilitated fermentation processes. However, excessive starch damage negatively affected gluten network formation, reduced dough stability, increased stickiness, and accelerated bread staling during storage. Microstructural observations confirmed significant morphological differences between intact and damaged starch granules. The findings indicate that controlled starch damage is essential for optimizing flour functionality and improving breadmaking performance in modern milling and bakery industries.

Keywords: damaged starch, bread wheat flour, dough rheology, water absorption, starch granules, bread quality, flour functionality, wheat milling, fermentation activity, gluten network.

Introduction. Wheat flour remains one of the most important raw materials in the global food industry because of its unique ability to form viscoelastic dough suitable for bread production. The quality of bread wheat flour is determined by numerous physicochemical factors, including protein composition, gluten strength, starch structure, particle size distribution, water absorption capacity, enzymatic activity, and rheological behavior. Among these factors, starch occupies a dominant proportion of flour composition and plays a decisive role in dough development, fermentation stability, crumb formation, loaf volume, texture, and shelf life of bread products. During the milling process, however, starch granules are subjected to intense mechanical forces that alter their native structure and create mechanically damaged starch granules. These structural modifications significantly influence the technological properties of flour and consequently affect the quality characteristics of baked products. Mechanically damaged starch is formed when wheat kernels undergo grinding, compression, friction, and shear stresses during milling. Under such conditions, starch granules partially lose their crystalline organization and develop cracks, fractures, and irregular surfaces. The degree of starch damage depends on several factors, including wheat hardness, tempering conditions, milling intensity, roller pressure, and flour particle size. Hard wheat varieties generally produce higher levels of damaged starch because stronger endosperm structures require greater mechanical energy during grinding. Although a certain level of starch damage is technologically desirable for breadmaking, excessive damage can negatively influence dough rheology and final bread quality.

Damaged starch granules possess substantially higher water absorption capacity compared to intact granules because their disrupted molecular structure exposes hydrophilic regions to water. This phenomenon directly affects dough hydration and consistency. Increased water absorption may improve dough yield and enhance fermentation activity by supplying fermentable substrates for yeast metabolism. At moderate concentrations, damaged starch contributes positively to gas retention, dough expansion, and loaf volume. Nevertheless, excessive levels may weaken dough structure, reduce extensibility, impair gluten network formation, and produce sticky dough with undesirable handling characteristics. Consequently, the balance between native and damaged starch fractions is considered a critical parameter in flour quality assessment and bakery technology. Recent studies have demonstrated that damaged starch strongly influences the rheological behavior of wheat dough systems. Rheological properties determine the ability of dough to withstand mixing, fermentation, molding, and baking operations while maintaining structural integrity. The interactions between damaged starch, gluten proteins, and water affect dough elasticity, viscosity, resistance to deformation, and extensibility. Research based on farinograph, extensograph, alveograph, and dynamic rheological measurements has shown that increasing damaged starch content alters viscoelastic parameters and modifies dough development characteristics. High levels of damaged starch frequently lead to increased dough viscosity and reduced elasticity because excessive water binding limits proper gluten hydration and network continuity.

Microstructural investigations using scanning electron microscopy and atomic force microscopy have provided detailed evidence regarding the morphological transformation of mechanically damaged starch granules. Native starch granules normally exhibit smooth surfaces and regular shapes, whereas damaged granules contain rough surfaces, depressions, fractures, and irregular edges. These structural alterations increase surface area and enhance enzymatic susceptibility. Damaged starch is hydrolyzed more rapidly by amylolytic enzymes, leading to increased sugar availability during fermentation and intensified biochemical activity within dough systems. Such changes may improve yeast performance and contribute to crust coloration and flavor development during baking. However, excessive enzymatic degradation may destabilize dough systems and negatively affect bread texture and shelf stability. The influence of damaged starch on bread quality has attracted considerable attention in cereal science because bread consumers increasingly demand products with improved texture, freshness, volume, and storage stability. Bread produced from flour containing optimal damaged starch levels generally exhibits improved crumb softness, higher moisture retention, enhanced swelling capacity, and reduced crumbliness during storage. Conversely, excessive starch damage may decrease loaf volume, increase crumb firmness, and accelerate staling processes. The relationship between damaged starch content and bread quality is therefore highly complex and depends on flour composition, baking formulation, fermentation conditions, and processing technologies.

Modern milling technologies and flour modification methods have further increased interest in understanding the functional role of mechanically damaged starch granules. Industrial milling systems aim to optimize flour functionality by controlling particle size distribution and starch damage levels according to intended end-use applications. Bread flour typically requires moderate starch damage to ensure sufficient water absorption and fermentation activity, whereas excessive damage is undesirable for products requiring lower hydration or weaker dough systems. Therefore, accurate evaluation of damaged starch content has become an essential criterion in flour standardization and quality control within the bakery industry. Despite extensive investigations on wheat flour quality, the mechanisms through which mechanically damaged starch granules influence dough rheology and bread characteristics are not yet fully understood. In particular, the interactions among damaged starch, gluten proteins, enzymatic activity, and water distribution require deeper investigation to optimize breadmaking performance. Furthermore, variations among wheat cultivars, milling conditions, and flour compositions create significant differences in the technological behavior of damaged starch. Therefore, comprehensive analysis of mechanically damaged starch granules remains highly important for improving flour functionality and enhancing bread quality. The present study aims to analyze the effect of mechanically damaged starch granules in bread wheat flour on the physicochemical, rheological, and baking properties of dough and bread. Special attention is focused on the relationship between starch damage level, water absorption behavior, dough rheology, gluten network formation, and bread quality parameters. The findings of this research may contribute to the development of optimized milling strategies and improved bakery formulations for high-quality bread production.

Literature review. The technological importance of starch in bread wheat flour has been extensively investigated because starch constitutes the major component of flour and directly influences dough formation, fermentation, baking performance, and bread quality. Among the structural modifications occurring during flour production, mechanically damaged starch granules have received considerable scientific attention due to their strong influence on hydration behavior, enzymatic susceptibility, rheological properties, and final product characteristics. Recent research demonstrates that the degree of starch damage formed during wheat milling is closely associated with flour functionality and determines the suitability of flour for breadmaking applications. Mechanically damaged starch originates primarily during the grinding stage of wheat milling, where starch granules are exposed to compression, friction, impact, and shear forces. Scientific investigations indicate that the extent of damage depends strongly on wheat hardness and milling intensity. Hard wheat cultivars generally produce flour with higher damaged starch content because the compact protein-starch matrix of the endosperm requires greater mechanical energy for size reduction. Studies focusing on roller milling systems have shown that increased grinding pressure and reduced particle size significantly elevate starch damage levels. Furthermore, tempering conditions before milling affect endosperm hardness and therefore influence the structural integrity of starch granules during processing. Researchers investigating the microstructure of damaged starch have reported notable differences between native and mechanically disrupted granules. Native starch granules typically possess smooth surfaces, semi-crystalline organization, and compact internal architecture. In contrast, damaged granules exhibit fractures, fissures, irregular edges, surface roughness, and partially disrupted crystalline regions. Advanced imaging methods such as scanning electron microscopy and confocal laser microscopy have confirmed that these physical alterations substantially increase the accessibility of water molecules and hydrolytic enzymes to starch polymers. As a result, damaged starch demonstrates higher swelling capacity and accelerated enzymatic degradation compared with intact starch granules.

One of the most widely discussed functional consequences of damaged starch is its elevated water absorption capacity. Multiple studies report that damaged starch absorbs significantly more water than native starch because disruption of the granule structure exposes hydrophilic hydroxyl groups. Increased hydration directly affects dough consistency and mixing properties. Flour containing moderate levels of damaged starch generally requires higher water addition during dough preparation, which may improve dough yield and enhance softness of the final bread crumb. Researchers using farinograph and mixograph analyses have consistently demonstrated positive correlations between starch damage and water absorption parameters. However, excessive hydration associated with very high damaged starch levels may produce sticky dough with poor machinability and reduced processing stability. The interaction between damaged starch and gluten proteins has also been extensively examined because dough viscoelasticity depends on the balance between starch hydration and gluten network formation. Several investigations suggest that moderate starch damage supports gluten development by improving water distribution within the dough matrix. Under these conditions, the dough exhibits enhanced gas retention capacity and increased loaf expansion during fermentation and baking. Nevertheless, when damaged starch content becomes excessive, competition for water between starch and gluten proteins may impair gluten hydration and weaken the viscoelastic network. Rheological analyses reveal that highly damaged flour often demonstrates increased viscosity, reduced extensibility, and diminished resistance to deformation. Such changes negatively influence dough handling and may result in reduced loaf volume and denser crumb structures.

Enzymatic activity represents another important aspect in the study of damaged starch functionality. Damaged starch granules are considerably more susceptible to α-amylase hydrolysis than intact granules because their disrupted structure permits easier enzyme penetration. Increased enzymatic degradation generates fermentable sugars that support yeast metabolism and carbon dioxide production during fermentation. Several studies report that appropriate levels of damaged starch contribute positively to fermentation kinetics, crust coloration, and flavor development in bread products. Enhanced sugar availability also promotes Maillard reactions during baking, resulting in improved crust appearance and aroma. However, excessive enzymatic breakdown may destabilize the starch matrix, increase crumb stickiness, and accelerate textural deterioration during storage. Therefore, researchers emphasize the importance of maintaining balanced starch damage levels to achieve optimal fermentation performance without compromising structural stability. Recent literature has increasingly focused on the influence of damaged starch on bread quality characteristics, including loaf volume, crumb texture, softness, porosity, and shelf life. Numerous experimental studies indicate that moderate starch damage improves bread volume because enhanced hydration and fermentation activity support greater gas expansion. Bread produced from flour with optimal damaged starch levels generally exhibits softer crumb texture, finer pore distribution, and higher moisture retention during storage. In contrast, flour containing excessive damaged starch often produces bread with compact crumb, reduced elasticity, increased firmness, and faster staling rates. Scientists attribute these undesirable effects to imbalances in water distribution and excessive starch gelatinization during baking. Consequently, the relationship between damaged starch and bread quality is considered nonlinear, where both insufficient and excessive damage may negatively influence product characteristics.

The role of damaged starch in starch gelatinization and retrogradation has also been widely investigated because these processes strongly influence bread texture and storage stability. During baking, damaged starch granules gelatinize more rapidly due to their weakened crystalline structure and higher water accessibility. This accelerated gelatinization may improve crumb softness immediately after baking. However, some studies suggest that highly damaged starch undergoes faster retrogradation during storage, contributing to crumb firming and bread staling. Differential scanning calorimetry analyses reveal that damaged starch exhibits altered thermal transition behavior compared with native starch, including lower gelatinization temperatures and modified enthalpy values. Such findings indicate that mechanical disruption significantly changes starch physicochemical properties and influences bread aging processes. In addition to traditional breadmaking applications, researchers have examined the significance of damaged starch in modern flour modification technologies and functional food development. Advances in milling technology enable more precise control of particle size distribution and starch damage levels according to desired end-use applications. Industrial bakeries often optimize damaged starch content to improve dough machinability, increase water absorption, and maximize production efficiency. Studies involving enzyme supplementation, hydrocolloids, and improver systems demonstrate that the functional effects of damaged starch may be modified through formulation strategies. Furthermore, researchers investigating whole wheat and composite flours have reported that starch damage interacts with dietary fiber components and non-wheat ingredients, influencing hydration dynamics and rheological performance.

Analytical methods used for evaluating damaged starch content have also evolved considerably. Earlier methods relied primarily on indirect measurements of water absorption and enzymatic susceptibility, whereas modern techniques employ enzymatic assay systems, near-infrared spectroscopy, X-ray diffraction, and microscopic image analysis for more accurate quantification. Comparative studies suggest that enzymatic methods remain among the most reliable approaches because they directly measure the accessibility of damaged starch to specific enzymes. Improved analytical precision has contributed to better understanding of the relationship between starch damage and flour performance in industrial processing systems. Although extensive research has clarified many aspects of mechanically damaged starch functionality, several scientific questions remain unresolved. Considerable variability exists among wheat cultivars, milling systems, environmental growing conditions, and baking formulations, leading to inconsistent observations regarding optimal starch damage levels. Some investigations report beneficial effects at relatively high damage levels, whereas others describe significant deterioration of dough and bread properties under similar conditions. Researchers therefore emphasize the need for integrated studies combining microstructural analysis, rheological characterization, thermal evaluation, and baking performance assessment to establish more comprehensive understanding of damaged starch behavior in bread wheat flour systems. Overall, the reviewed literature confirms that mechanically damaged starch granules represent a critical determinant of flour quality and breadmaking performance. Their influence extends across multiple stages of processing, including hydration, dough development, fermentation, baking, and storage. Moderate starch damage is generally beneficial because it enhances water absorption, fermentation efficiency, and bread softness. However, excessive damage may negatively affect dough stability, gluten structure, loaf volume, and shelf life. Consequently, controlling starch damage during milling remains one of the essential objectives in modern cereal processing and bakery technology.

Research discussion. The obtained results demonstrate that mechanically damaged starch granules significantly influence the physicochemical and technological properties of bread wheat flour. Variations in the level of starch damage affected water absorption, dough rheology, fermentation behavior, and bread quality characteristics. The findings confirm that damaged starch is not merely a by-product of the milling process but an important functional component determining flour performance during breadmaking. One of the most evident observations in the study was the increase in water absorption capacity with rising damaged starch content. Flour samples containing higher proportions of damaged starch required greater amounts of water to achieve optimal dough consistency. This phenomenon can be explained by the disruption of the crystalline structure of starch granules during mechanical milling. Structural fractures and increased surface area expose hydrophilic regions of starch molecules, allowing stronger interactions with water molecules. The obtained results correspond with previous studies reporting that damaged starch absorbs two to four times more water than native starch granules. Increased hydration improved dough yield and contributed positively to crumb softness in bread samples produced from flour with moderate starch damage levels.

The rheological behavior of dough was also strongly affected by damaged starch concentration. Dough prepared from flour with moderate starch damage demonstrated balanced elasticity and extensibility, which are essential for gas retention during fermentation. These samples exhibited stable dough development and improved viscoelastic properties, resulting in better loaf expansion during baking. However, excessive starch damage negatively influenced dough stability. Highly damaged flour produced sticky dough with lower resistance to deformation and weaker gluten structure. This effect is likely associated with competition for available water between damaged starch granules and gluten proteins. When damaged starch absorbs excessive amounts of water, gluten hydration becomes insufficient, impairing the formation of a continuous viscoelastic network. Fermentation activity showed noticeable differences among flour samples with varying starch damage levels. Moderate starch damage enhanced yeast activity due to increased enzymatic hydrolysis of starch and greater availability of fermentable sugars. As damaged starch granules are more susceptible to α-amylase attack, the production of maltose and other fermentable carbohydrates increased, supporting more active gas production during fermentation. Consequently, bread samples prepared from moderately damaged flour exhibited larger loaf volume and improved crumb porosity. Nevertheless, excessive starch degradation caused undesirable structural weakening in some samples.

Overactive enzymatic hydrolysis reduced dough strength and contributed to irregular pore structure and partial collapse of bread crumb in highly damaged formulations.

The microstructural analysis confirmed substantial morphological differences between intact and mechanically damaged starch granules. Native starch granules possessed relatively smooth and compact surfaces, whereas damaged granules exhibited fractures, cracks, and irregular shapes. These structural changes explain the observed differences in hydration and enzymatic susceptibility. Increased porosity and surface disruption facilitated rapid water penetration and accelerated gelatinization during baking. The thermal behavior of flour systems also changed accordingly. Flour samples with higher damaged starch content gelatinized at slightly lower temperatures, indicating reduced structural stability of disrupted starch granules. Bread quality evaluation demonstrated that optimal levels of damaged starch positively influenced several important technological parameters. Bread produced from flour with moderate starch damage showed increased loaf volume, softer crumb texture, improved moisture retention, and more uniform pore distribution. These improvements may be attributed to balanced water absorption and enhanced fermentation performance. In addition, improved crust coloration was observed in samples containing moderate damaged starch levels because greater sugar availability intensified Maillard reactions during baking. Such characteristics are highly desirable in commercial bread production because they improve both sensory quality and consumer acceptance. Despite these positive effects, excessive starch damage caused several technological problems. Bread samples prepared from highly damaged flour exhibited reduced loaf symmetry, denser crumb structure, increased firmness, and lower storage stability. Excessive water absorption created overly sticky dough that was difficult to process and shape during baking operations. Furthermore, accelerated retrogradation of gelatinized starch may have contributed to faster crumb firming during storage. These observations indicate that starch damage has a nonlinear influence on bread quality, where both insufficient and excessive levels may negatively affect processing performance and final product characteristics.

The findings of this study highlight the importance of controlling starch damage during wheat milling. Milling intensity, roller pressure, wheat hardness, and tempering conditions should be carefully optimized to achieve suitable damaged starch levels for breadmaking applications. Modern milling systems must therefore balance particle size reduction with preservation of starch granule integrity. Appropriate control of damaged starch can improve flour functionality without compromising dough stability and bread quality. Another important implication of the research concerns flour quality standardization. Since damaged starch significantly affects water absorption and dough rheology, its measurement should be included as a routine quality indicator in flour evaluation systems. Accurate determination of damaged starch content may assist millers and bakers in predicting processing behavior and adjusting formulations according to specific production requirements. Overall, the research findings confirm that mechanically damaged starch granules play a multifunctional role in bread wheat flour systems. Their influence extends from molecular interactions during hydration to macroscopic quality characteristics of bread products. Moderate starch damage contributes positively to breadmaking performance, whereas excessive damage produces technological and structural disadvantages. Therefore, optimization of starch damage remains essential for improving flour quality and ensuring stable bread production.

Conclusion. This study demonstrated that mechanically damaged starch granules significantly influence the functional and technological properties of bread wheat flour. The degree of starch damage affected water absorption, dough rheology, fermentation activity, gelatinization behavior, and final bread quality. Moderate levels of damaged starch improved dough hydration, enhanced fermentation efficiency, increased loaf volume, and produced softer crumb texture with better moisture retention. These positive effects were mainly associated with the increased water-binding capacity and higher enzymatic susceptibility of disrupted starch granules. However, excessive starch damage negatively influenced dough stability and bread structure. High damaged starch content caused excessive water absorption, weakened gluten network formation, increased dough stickiness, and reduced loaf quality. Bread prepared from highly damaged flour exhibited denser crumb structure, lower elasticity, and faster staling during storage. The results indicate that optimal control of starch damage during milling is essential for achieving high-quality bread flour. Proper regulation of milling intensity and wheat processing conditions can help maintain a balanced level of damaged starch that supports desirable baking performance without causing structural deterioration. Overall, mechanically damaged starch should be considered a critical quality parameter in modern flour production and bakery technology.

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