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Original Article

Influence of enzymes and emulsifiers used as bread improvers on texture of sliced bread

Influencia de las enzimas y los emulsificantes utilizados como mejoradores de pan en la textura del pan molde

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Spanish version

Abstract

Introduction: Bread improvers based on emulsifiers and enzymes are widely used to enhance dough performance and delay staling; however, their synergistic effects on texture stability during storage are not yet fully understood.
Objective: To evaluate the effect of different combinations of emulsifiers and enzyme systems on dough properties, bread quality, and texture stability during storage.
Methodology: Six formulations combining Distilled Monoglycerides (DMG90), Sodium Stearoyl Lactylate (SSL), Diacetyl Tartaric Acid Esters of Mono- and Diglycerides (DATEM), soy lecithin, and two enzyme systems were evaluated and compared with a commercial bread improver. Dough properties were analyzed using farinograph parameters, while bread quality was assessed through physicochemical measurements, color analysis, texture profile analysis, and firmness during storage.
Results: The DMG90–SSL–maltogenic □-amylase formulation showed the best performance, with greater dough stability and development time, as well as lower crumb hardness and firmness. No significant differences were observed in moisture content or specific volume. During storage, this formulation exhibited lower firmness than the commercial improver, highlighting a synergistic effect between emulsifiers and enzymes.
Conclusions: The DMG90–SSL–maltogenic □-amylase system represents a technologically viable alternative to commercial bread improvers, improving dough performance and preserving bread softness during storage.

Keywords: Softness; Farinograph; Bread making; Crumb texture.

Resumen

Introducción: Los mejoradores de pan a base de emulsificantes y enzimas se utilizan para mejorar el comportamiento de la masa y retrasar el endurecimiento; sin embargo, sus efectos sinérgicos sobre la estabilidad de la textura durante el almacenamiento aún no se conocen con suficiente precisión.
Objetivo: Evaluar el efecto de diferentes combinaciones de emulsificantes y sistemas enzimáticos sobre las propiedades de la masa, la calidad del pan y la estabilidad de su textura durante el almacenamiento.
Metodología: Se evaluaron seis formulaciones que combinaban Monoglicéridos Destilados (DMG90), Estearoil Lactilato de Sodio (SSL), Ésteres de Ácido Tartárico Diacetílico (DATEM), lecitina de soja y dos sistemas enzimáticos, en comparación con un mejorante comercial. Las propiedades de la masa se analizaron mediante parámetros del farinógrafo, mientras que la calidad del pan se evaluó mediante mediciones fisicoquímicas, color, perfil de textura y firmeza durante el almacenamiento.
Resultados: La formulación DMG90–SSL–□-amilasa maltogénica presentó el mejor rendimiento, con mayor estabilidad y tiempo de desarrollo de la masa, así como menor dureza y firmeza de la miga. No se observaron diferencias significativas en humedad ni volumen específico. Durante el almacenamiento, esta formulación presentó menor firmeza que el mejorador comercial, evidenciando un efecto sinérgico entre emulsificantes y enzimas.
Conclusiones: El sistema DMG90–SSL–□-amilasa maltogénica constituye una alternativa tecnológica viable a los mejorantes comerciales, al mejorar el comportamiento de la masa y conservar la suavidad del pan durante el almacenamiento.

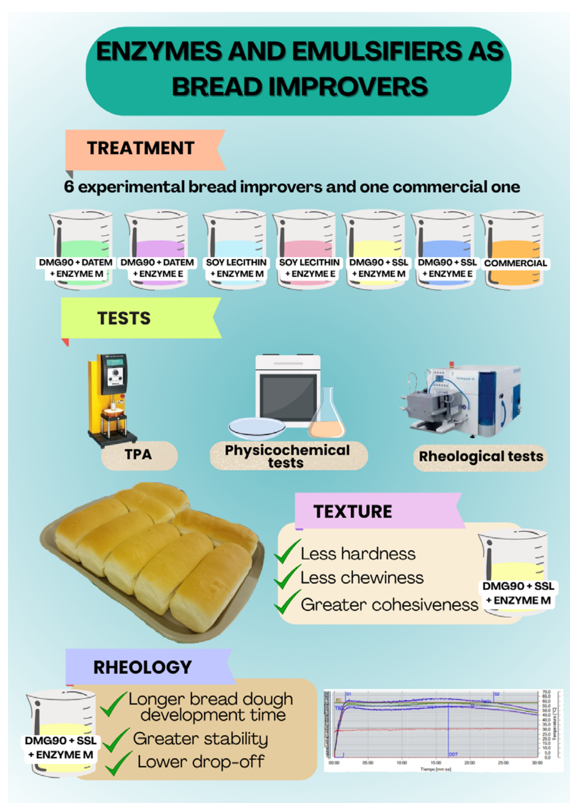
Palabras clave: Suavidad; Farinógrafo; Elaboración de pan; Textura de la miga.

Why was the study conducted?
The study was conducted to evaluate the effects of different combinations of emulsifiers and enzyme systems on dough rheology, bread quality, and texture stability during storage. The research aimed to identify an improver formulation capable of improving dough performance and maintaining crumb softness during storage, while providing a potential technological alternative to a commercial bread improver.

What were the key findings?
The DG90–SSL–M formulation, combining distilled monoglycerides (DG90), sodium stearoyl lactylate (SSL), and maltogenic α-amylase, showed the best overall performance. This formulation exhibited favorable dough development and stability characteristics and produced bread with lower hardness and crumb firmness than most of the experimental formulations. During storage, DG90–SSL–M maintained lower hardness and crumb firmness than the commercial improver, indicating better preservation of crumb softness and texture stability.

What do these findings contribute?
The findings provide applied evidence that tailored combinations of emulsifiers and maltogenic α-amylase can improve dough performance and contribute to maintaining bread texture during storage. The results provide useful insights for the formulation and optimization of bread improvers and demonstrate the potential of these systems as technological alternatives to commercial improvers, particularly for improving crumb softness and texture stability during storage.

Graphical Abstract



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Introduction

Sliced bread is central to industrial baking due to its high demand and nutritional value. A staple food, it is consumed on a massive scale and is particularly valued for its soft crumb, neutral flavor, and long shelf life. However, its production faces several technological challenges. Bread stales during storage due to starch retrogradation, which hardens the crumb and reduces freshness (1). Additives are used to counteract this phenomenon by retaining moisture and delaying hardening. Another key challenge is producing an uniform product consistently, as consumers demand breads with high volume, controlled porosity, and a consistent texture. This demand for consistent quality and a long shelf life has driven the widespread use of technological additives, such as emulsifiers, enzymes, and oxidants, in formulation (2). Improvers also seek protection against microbial deterioration and optimization of process performance.

Improvers are mixtures of functional ingredients designed to optimize the properties of dough and bread (3). In general, they contain enzymes, emulsifiers, oxidizing agents, and other specific additives. Each component performs a particular function: enzymes modulate gluten extensibility and starch preservation. Emulsifiers reinforce the gluten network and stabilize the dough, and oxidizing agents strengthen gluten protein bonds. Together, these additives enable achieving the desired volume, obtaining an airy, tender crumb, and prolonging product freshness (2).

Among these components, emulsifiers play a crucial role in the structural and sensory quality of bread. They are surfactant additives that facilitate the incorporation of fats and carbohydrates into the dough. In industrial baking, the most commonly used are sodium SSL and DATEM. Both are associated with significant increases in bread volume and finer, more uniform crumbs (4). These anionic emulsifiers enhance the interaction among fats, gluten and starch, strengthening the protein network during kneading. In addition, during baking, they form insoluble complexes with amylose, slowing starch retrogradation and delaying crumb hardening, keeping the bread soft for longer. In contrast, natural emulsifiers such as soy lecithin also improve bread quality, although through different mechanisms. It has been reported to increase specific volume and produce a softer crumb compared to DATEM (5).

In turn, enzymes act during mixing and fermentation by modifying the macromolecular structures of flour. Amylase is the most widely used, as it partially hydrolyzes starch, transforming it into simple sugars that feed the yeast and improve fermentation, crust color, and moisture retention in the crumb (1). In appropriate doses, amylases help delay moisture loss, thereby prolonging bread's shelf life. Both enzymes and emulsifiers can act in a complementary or even substitutive manner in improvers.

In recent years, various studies have explored the combined use of enzymes and emulsifiers. Chowdhury et al. (1) presented a comprehensive review of enzyme applications in baking and highlighted the role of α-amylases, xylanases, lipases, and other enzymes in dough development and shelf-life extension. In the field of emulsifiers, Valsalan et al. (6) demonstrated that treating ancient cereal flours with SSL, in combination with extrusion processes, improves water absorption and dough stability, resulting in breads with greater volume and better texture. Similarly, Cao et

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al. (7) demonstrated that the use of emulsifiers and enzymes in bread enriched with potato pulp increases the elasticity and resistance of the dough due to the strengthening of the gluten network.

Despite these advances, gaps remain in the literature on conventional sliced bread. Most studies focus on specialty products or on the isolated evaluation of enzymes or emulsifiers. There are limited studies comparing several improver systems under identical experimental conditions. Therefore, research into novel formulations that integrate both types of additives synergistically is warranted to optimize the texture, freshness, and overall quality of bread. The objective of this study was to evaluate the physicochemical, structural, and rheological properties of sliced bread made with different combinations of improvers and emulsifiers, including DATEM, SSL, soy lecithin, and DMG90 monoglyceride, and two types of enzymes (E and M).

Materials and methods

Materials

The raw materials used in the preparation of the improver formulations were guar gum, Carboxymethylcellulose (CMC) (Gelycel F1 1500, Amtex, Medellín, Colombia), and soy lecithin, which were commercially sourced and provided by TECNAS S.A. (Itagüí, Colombia); cassava starch (Gel®Starch XP) was supplied by Poltec SAS (La Estrella, Colombia); enzyme M (Alphamalt Fresh 15, Mühlenchemie, Ahrensburg, Germany) 3000-4000 U per kg of flour and enzyme E (Alphase Extra Bake, Eurogerm S.A.S, Saint Apollinaire, France) 2000-3000 U per kg of flour. The emulsifier Monoestearol 95 (DMG90) was supplied by Nutresol (Cartagena, Colombia) and was used in all the improvers formulated in the laboratory. It was mixed with two other emulsifiers: diacetyl tartaric acid ester of mono- and diglycerides (DATEM) and stearoyl-2-lactylate sodium (SSL) (Protécnica Ingeniería, Yumbo, Colombia), at a 1:1 ratio. In addition, a commercial bread improver (Magimix, Lesaffre Colombia, Cali, Colombia) was compared with the improvers produced in this study.

Improvers

Six different improvers or treatments were prepared by varying the types of emulsifiers and enzymes used in their production. They were then compared to a treatment using a commercial improver. Samples were subjected to various measurements to evaluate their textural, physicochemical, and farinographic properties.

The improver is formulated with a specific proportion of different ingredients: 50% guar gum, 10% sodium carboxymethylcellulose (CMC), 20% emulsifiers, 10% cassava starch, and 10% enzymes. Based on this formulation, six types of improvers were developed by varying the types of emulsifiers and enzymes used (Table 1). Texture tests, physical analyses, and farinograph tests were performed on these six treatments, and the results were compared to those obtained from a commercial improver.

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Table 1. Composition of the experimental bread improvers.

Treatment	Emulsifier(s) (20%)	Enzyme (10%)*	Constant ingredients (%)
SOYLEC-M	Soy lecithin	M	Guar gum (50), CMC (10), cassava starch (10)
SOYLEC-E	Soy lecithin	E	Guar gum (50), CMC (10), cassava starch (10)
DMG90-DATEM-M	DMG90 + DATEM	M	Guar gum (50), CMC (10), cassava starch (10)
DMG90-DATEM-E	DMG90 + DATEM	E	Guar gum (50), CMC (10), cassava starch (10)
DMG90-SSL-M	DMG90 + SSL	M	Guar gum (50), CMC (10), cassava starch (10)
DMG90-SSL-E	DMG90 + SSL	E	Guar gum (50), CMC (10), cassava starch (10)

(*)M is a maltogenic α-amylase enzyme, brand Alphamalt Fresh 15, from Mühlenchemie and E is a multi-enzyme blend, brand Alphase Extra Bake, from Eurogerm

Farinographic properties

The quality of the dough was determined by estimating its rheological properties using a farinograph (Farinógrafo®-AT, Brabender® GmbH & Co. KG, Duisburg, Germany). Different improver formulations were used at a 1% ratio based on the amount of wheat flour. Dough parameters were evaluated according to the AACC 59-21 method (8), including dough development time (DDT), water absorption (%WA), stability (S), mixing tolerance index (MTI), and drop-off (D).

Bread making

The formulation of the bread loaf was based on the amount of wheat flour as follows: 1230 g of wheat flour (Tres Castillos, Cartagena, Colombia), 56 g of sugar, 113 g of margarine (Astra, Sigra, Bogotá, Colombia), 12 g of dry yeast (Angel Yeast, Yichang, China), 20 g of salt, 681 g of water, and 40 g of egg. The developed improvers and the commercial improver were added to the bread formulation in a proportion of 1% based on the amount of wheat flour (1230 g). Dry ingredients and margarine were blended together using a mixer (Javar B12LR110V/60/1F10Lt, Bogotá, Colombia) for less than one minute. Then, water, milk, and egg were added, and the mixture was kneaded until a homogeneous dough formed, a process that took around 35 min. The dough was divided into 14 equal portions (approx. 150 g each) and left to rest for 10 min. Subsequently, the portions were kneaded, rolled, and placed in molds. The dough samples were fermented for 45 min in a fermentation chamber and then baked in a gas oven (GFO-4B, Guangzhou Youjia Machinery Co., China) at 180 °C top heat and 240 °C bottom heat for 22 min. After baking, the loaves were cooled to room temperature for 60 min before being packed for subsequent characterization through quality and texture tests.

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Textural properties

The crumb firmness of the sliced bread samples made with the different improvers was determined according to the AACC 74-09 standard method (8). Compression strength tests were performed using a texturometer (CT3 Brookfield, Toronto, Canada). Test parameters were a pre-test speed of 1.0 mm/s, a post-test speed of 10 mm/s, a test speed of 1.7 mm/s, and a compression distance of 10 mm (40% strain). A cylindrical probe with a diameter of 20 mm was used, and each sample had a thickness of approximately 25 mm. For texture profile analysis (TPA), a sample slice with a thickness of 80 mm and a width of 50 mm was used. The same texture analyzer was employed, which was equipped with a 50 kg load cell and a rectangular probe. The parameters for this test were a pre-test speed of 2.0 mm/s, a post-test speed of 5 mm/s, a test speed of 2 mm/s, and a compression distance of 48 mm (60% strain). In both tests, 14 samples of each model were measured, obtaining data on hardness (N), springiness (m), cohesiveness, chewiness (J), and crumb firmness (N).

Physical-chemical properties

The specific volume of the breads was calculated using the 10-05.01 millet seed displacement method (8) . Yield (%) was calculated as the ratio between the weight of the final product and the weight of the dough (9). The moisture content of the bread was determined by analyzing triplicate samples from both the breads made with the commercial improver and those formulated in the laboratory. Moisture content was determined using the AACC 44-19 method (8). This measurement was performed separately for the bread crumbs and the crust. The water activity of the samples was determined using a dew-point hygrometer at 28 °C (Aqualab Series 3TE, Decagon Devices, Pullman, WA, USA). This equipment measures the equilibrium moisture content of a product, which is determined by the partial pressure of water vapor on its surface (9).

Porosity

The bread’s porosity was evaluated using image analysis. Samples were cut into 2.5 cm thick slices and placed on the glass of a scanner. The scan was performed at 600 dpi. The images obtained were analyzed using ImageJ software, which distinguishes between pores and solid regions based on contrast. Initially, the scanned color image was converted to an 8-bit grayscale (10). Subsequently, using bars of known lengths (1 cm), the pixel values were converted into distance units. The method was used to examine the number of pores and the pore area.

Color

Color properties were evaluated using a sphere spectrocolorimeter (SP64, X-Rite Inc., MI, USA) by determining XYZ tristimulus values, which were subsequently converted into CIELab* color coordinates. In this color space, L* represents lightness; a*, redness (+a*) or greenness (−a*); and b*, yellowness (+b*) or blueness (−b*). From these values, the parameters h (hue) and C (saturation) were calculated using equations 1 and 2 (11).

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$$h = tan^{-1}(\frac{b}{a}) \quad [1]$$

$$C = \sqrt{(a)^2 + (b)^2} \quad [2]$$

Statistical analysis

Fourteen loaves of bread were produced for each evaluated improver. Seven loaves were allocated to texture analyses, whereas the remaining seven loaves were used for physicochemical and structural analyses. From each loaf assigned to texture analysis, two slices were collected: one slice was used for texture profile analysis (TPA), and the other for crumb firmness measurement, resulting in seven experimental replicates for each test. Instrumental measurements were performed in triplicate on each slice. The loaf was considered the experimental unit, whereas the instrumental measurements performed on each slice were treated as subsamples. Data were analyzed by analysis of variance (ANOVA). Whenever a significant treatment effect was detected, means were compared using Fisher's least significant difference (LSD) test. All statistical analyses were performed using Statgraphics Centurion XVIII at a significance level of $\alpha = 0.05$.

Results and discussion

Farinographic properties

Table 2 shows the effects of different improvers on the behavior of bread dough during kneading, evaluating parameters such as dough development time (DDT), water absorption (%), stability, tolerance index (MTI), and drop-off. DMG90-SSL-M treatment had the longest dough development time; therefore, it was more resistant to kneading and had a stronger gluten network. In contrast, bread with the commercial improver had the shortest development time, suggesting a less structured dough. These results are consistent with those of Kumar and Sharma (12), who reported that anionic emulsifiers such as SSL and DATEM enhance dough tolerance and promote gluten aggregation via electrostatic interactions, thereby strengthening the protein matrix and improving resistance during mixing. All treatments showed no significant differences in water absorption. This is consistent with studies reporting that emulsifiers such as SSL and DATEM generally exert minimal influence on farinographic water absorption, although they enhance dough stability and promote more uniform gluten hydration during mixing by strengthening protein–lipid interactions and improving water distribution within the matrix (2, 12).

DMG90-SSL-M showed numerically higher stability value, although no significant differences were detected among treatments, suggesting stronger dough and greater tolerance to over-kneading. Emulsifiers can improve gluten stability and make the dough more resistant to mechanical stress-induced breakage. SOYLEC-E tended to present lower MTI values; however, it was statistically similar to several other treatments, indicating less sensitivity to over-kneading. Synergistic treatment with emulsifiers enhances the functional properties of wheat proteins, reinforcing

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the gluten network and increasing resistance to deformation during mixing and proofing, which is consistent with improved dough stability indicated by reduced MTI values (6). The commercial improver also showed numerically lower MTI, although no significant differences were detected to several other treatments. This is undesirable because it makes the dough difficult to handle and results in bread with a very dense texture. Furthermore, the DMG90-DATEM-E treatment showed a numerically higher MTI of slightly above 30 BU, indicating that the flour is suitable for bread making. The MTI is desirable with values close to 30 BU but below 50 BU, as confirmed by Tebben et al. (2); it indicates a more stable and uniform dough. Although the SOYLEC-E and DMG90-SSL-M treatments had the lowest drop-off values, indicating less loss of consistency at the end of kneading, this difference was not significant compared to the other treatments. However, a tendency towards higher drop-off was observed in the commercial sample. According to AbuDujayn et al. (13), a low drop-off in the farinograph curve represents better plastic behavior of the dough. The DMG90-SSL-M treatment performed best in the rheological tests. It had the longest development time, highest stability, lowest MTI, and lowest drop-off value. These results indicate that stronger, more stable, and more resistant dough was obtained. Table 2.

Table 2. Rheological characteristics of bread made with different improvers

TREATMENT	DMG90-DATEM - E	DMG90-DATEM- M	SOYLEC - M	SOYLEC-E	DMG90-SSL-M	DMG90-SSL - E	COMMERCIAL
DDT (min)	15.28 ± 0.84 b *	14.67 ± 0.93 b	15.70 ± 1.11 b	16.13 ± 0.79 b	17.17 ± 0.29 b	16.49 ± 0.56 b	6.105 ± 0.404 a
Water absorption (%)	60.03 ± 0.06 a	60.03 ± 0.06 a	60.03 ± 0.06 a	60.067 ± 0.06 a	60.07 ± 0.06 a	60.0 ± 0.0 a	60.0 ± 0.0 a
Stability (min)	17.19 ± 2.48 a	20.48 ± 1.84 ab	20.58 ± 2.31 ab	20.91 ± 2.56 ab	22.49 ± 0.55 b	18.72 ± 3.73 ab	18.25 ± 0.69 a
. MTI (BU)	33.33 ± 8.02 c	21.33 ± 4.93 ab	24.67 ± 9.87 abc	20.0 ± 2.0 ab	22.67 ± 0.58 abc	29.67 ± 4.51 bc	16.67 ± 10.60 a
Drop- off. (BU)	24.68 ± 1.15 bc	19.33 ± 7.09 b	16.67 ± 6.66 ab	10.67 ± 2.08 a	9.67± 1.53 a	17.33 ± 6.03 ab	31.67± 4.16 c

(*) Values in the same row followed by different letters are significantly different. Dough development time (DDT). Mixing tolerance index (MTI), and drop-off were expressed in Brabender Units (BU)

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Physicochemical tests

Table 3 shows the physical characteristics of sliced bread made with seven types of improvers. It shows that most of the evaluated parameters did not differ significantly among treatments. This suggests that the improvers had similar effects on the final product's physical properties. In terms of water activity (a_w), the values ranged from 0.931 to 0.945, with very similar means across treatments. These values are consistent with those reported by Vásquez-Lara et al. (14), who evaluated the water activity in breads made with a substitution of heat-treated oat flour and obtained a_w values of 0.952-0.962. This allows us to conclude that, regardless of the type of improver incorporated, the water activity of bread is not significantly altered; therefore, these additives do not affect the availability of free water in the product.

No significant differences in specific volume were observed among treatments, indicating that, in general, the improvers used had a similar effect on this property. SSL and DATEM improvers help increase specific volume in bread by improving the crumb's internal structure, promoting gas retention in the dough, and resulting in more aerated breads without altering their moisture content (4). These findings align with those of Ahmed et al. (15). When they experimented with incorporating chia flour and different levels of soy lecithin into bread, they noted clear improvements in the product's freshness and volume: as the amount of lecithin in the formula increased, the bread became spongier with a soft, moist crumb.

Regarding crumb moisture, two homogeneous groups were identified, while crust moisture did not differ significantly among treatments. Similar trends have been reported in the literature evaluating the effect of emulsifiers on bread systems, where SSL, DATEM, and mono- and diglycerides improved structural properties and delayed crumb firming without causing significant differences in overall moisture content. These findings suggest that emulsifiers primarily influence water distribution and starch–gluten interactions rather than total moisture retention (2, 6). The use of emulsifiers improved the texture and volume of the bread, without altering the crumb moisture content across treatments. Yields did not differ significantly among treatments, ranging from 87.72% to 90.09%. These results were slightly higher than those reported by Lopez-Tenorio et al. (16), who observed yields of 79.2% to 81.7% in gluten-free cheese breads made with emulsifiers such as DATEM and SSL.

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Table 3. Physical characteristics of sliced bread made with 7 types of improvers.

TREATMENT	DMG90-DATEM -E	DMG90-DATEM-M	SOYLEC - M	SOYLEC-E	DMG90-SSL-M	DMG90-SSL - E	COMMERCIAL
a_w	0.93 ±0.01 ^{a} *	0.93 ±0.01 ^{a}	0.94 ± 0.01 ^{a}	0.94 ± 0.01 ^{a}	0.94 ± 0.01 ^{a}	0.94 ± 0.01 ^{a}	0.94 ± 0.00 ^{a}
Specific volume (mL/g)	5.59 ±0.22 ^{a}	5.83 ±0.09 ^{a}	5.50 ± 0.19 ^{a}	5.41 ± 0.71 ^{a}	6.09 ± 0.88 ^{a}	5.69 ± 0.41 ^{a}	6.122 ± 0.842 ^{a}
Moisture content in the crumb (%)	30.19 ± 0.02 ^{ab}	28.37 ±0.01 ^{a}	31.83 ± 0.01 ^{b}	30.89 ± 0.01 ^{ab}	31.16 ± 0.02 ^{ab}	29.58 ± 0.02 ^{ab}	30.86 ± 0.02 ^{ab}
Moisture content in the crust (%)	28.23 ±0.02 ^{a}	28.48 ± 0.03 ^{a}	29.19 ± 0.01 ^{a}	28.38 ±0.02 ^{a}		27.86 ± 0.02 ^{a}	29.81± 0.03 ^{a}
Yields (%)	88.22% ± 0.02 ^{a}	90.01 % ± 0.02 ^{a}	90.10 ±0.01 ^{a}	87.72 ± 0.02 ^{a}	88.73 ± 0.01 ^{a}	88.88 ± 0.03 ^{a}	89.22 ± 0.10 ^{a}

(*) Values in the same row followed by different letters are significantly different.

Table 4 shows how the porosity of sliced bread varies with the type of improver used during preparation. In general, all treatments generated similar amounts of pores, with totals ranging from 720.52 to 836.87. However, bread made with SOYLEC-E and the commercial improver had a greater number of pores, with a statistical difference from the DMG90-DATEM-M, allowing better aeration in the crumb. Most pores in all treatments were small (0-0.01 cm^2), accounting for 70-75% of the total. The SOYLEC-M treatment stood out in this regard, achieving the highest number of pores in the 0-0.01 range, suggesting a finer, more uniform crumb.

In terms of average porosity, the numerically highest value was observed in bread made with SOYLEC-E, indicating a more open and lighter structure. It was followed by the DMG90-SSL-M and DMG90-DATEM-M treatments, which also had good aeration. In contrast, the DMG90-DATEM-E treatment showed the lowest value, suggesting a denser crumb or less pore expansion. Although some differences were observed among treatments, most were not statistically significant. This means that, although there are variations in the numbers, they are not always marked enough to consider that one treatment was clearly better than the others. Cao et al. (7) found that adding 0.65% soy lecithin to the potato pulp bread formulation significantly improved porosity, both immediately after baking and during storage. The resulting crumb showed well-distributed pores and a smoother, more compact texture than bread without this ingredient. These results also coincide with those of Codină and Mironeasa (17), who, when using soy lecithin at moderate levels (0.2%-1%), found that it improved bread performance by slightly increasing specific volume, retaining moisture better, and achieving a more uniform, smoother crumb.

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Table 4. Porosity of sliced bread made with different improvers.

TREATMENT		DMG90-DATEM - E		DMG90-DATEM- M		SOYLEC - M		SOYLEC- E		DMG90-SSL-M		DMG90-SSL - E		COMMERCIAL	
		N° pores	%	N° pores	%	N° pores	%	N° pores	%	N° pores	%	N° pores	%	N° pores	%
AREA	0 – 0.01	557.03 ± 72.82 ab	74.51	534.06 ± 90.96 a	74.12	569.27 ± 112.86 ab	73.61	631.73 ± 197.58 c	75.48	573.0 ± 76.24 ab	72.86	567.83 ± 66.61 ab	73.74	592.3 ± 98.71 bc	73.56
	0.011 – 0.05	153.73 ± 27.80 ab	20.56	137.32± 31.61 a	19.06	158.93 ± 38.58 b	20.55	165.73 ± 54.70 bc	19.80	157.87 ± 27.35 b	20.07	162.47 ± 22.48 b	21.10	179.77 ± 18.16 c	22.33
	0.051 – 0.1	28.40 ± 4.77 a	3.80	33.10 ± 6.28 c	4.59	32.8 ± 6.34 c	4.24	28.57 ± 5.73 ab	3.41	38.87 ± 10.74 d	4.94	31.93 ± 5.65 bc	4.14	27.07 ± 6.32 a	3.36
	0.11 – 0.5	8.37 ± 4.33 ab	1.12	15.84 ± 4.33 d	2.20	12.2 ± 6.56 c	1.58	10.7 ± 6.46 bc	1.28	16.73 ± 8.52 d	2.13	7.833 ± 2.61 a	1.02	6.0 ± 3.14 a	0.74
TOTAL PORES		747.57 ± 96.60 ab		720.52 ± 113.22 a		773.4 ± 145.93 abc		836.87 ± 246.06 c		786.47 ± 99.54 abc		770.07 ± 79.80 abc		805.17 ± 106.79 bc	
POROSITY (%)		34.14 ± 0.00 a		36.56 ± 0.01 ab		35.06 ± 0.02 ab		37.28 ± 0.03 b		36.43 ± 0.02 ab		34.82 ± 0.00 ab		35.39 ±0.01 ab	

(*) Values in the same row followed by different letters are significantly different.

Color characteristics

Table 5 shows the color parameters (L*, a*, b*, hue h, and saturation C) in bread made with different improvers. Significant differences were observed among treatments for most parameters, indicating that improvers influence the visual appearance of bread. In terms of lightness (L*), breads with SOYLEC-M and SOYLEC-E obtained the highest values, showing a lighter crumb, while DMG90-SSL-M and DMG90-DATEM-M produced the darkest breads. The a* value, associated with red tones, was lower in SOYLEC-M and higher in DMG90-DATEM-M, indicating greater red intensity in the latter. In b*, which represents the yellow component, the highest values corresponded to DMG90-DATEM-E, and the lowest to DMG90-SSL-M. Hue (h) was higher in SOYLEC-M, suggesting a tendency towards more yellow tones, while DMG90-SSL-M had the lowest hue. Finally, DMG90-DATEM-E showed the highest saturation (C) among the samples, in contrast to DMG90-SSL-M. Breads with lecithin (SOYLEC) tend to have a lighter crumb with less saturated hues, whereas improvers such as DATEM and SSL affect the hue and intensity of the color, and result in noticeable differences to the eye. Breads containing lecithin tend to exhibit higher L* values (lighter crumb), whereas DATEM and SSL may alter hue and chromaticity coordinates (a*, b*), producing perceptible differences in crumb color. Similar effects of emulsifiers on crumb color parameters (L*, a*, b*) have been reported by Yeşil and Levent (18), who observed significant differences in lightness and color attributes depending on the emulsifier used.

Table 5. Color parameters, L*, a*, b*, h, and C for bread made with different improvers

	DMG90-DATEM - E	DMG90-DATEM- M	SOYLEC - M	SOYLEC- E	DMG90-SSL-M	DMG90-SSL- E	COMMERCIAL
L*	61.13 ± 0.41 bc *	58.19 ± 0.36 a	63.27 ± 2.46 c	63.42 ± 0.79 c	58.88 ± 0.12 ab	60.05 ± 3.11 ab	60.12 ± 0.89 ab
a*	11.41 ± 0.76 bc	12.61 ± 0.93 c	9.20 ± 1.62 a	9.69 ± 1.93 ab	10.88 ± 0.77 abc	11.33 ± 1.25 abc	11.42 ± 0.65 bc
b*	31.42 ± 2.47 b	29.14 ± 1.80 ab	28.68 ± 2.0 ab	28.12 ± 3.0 ab	25.67 ± 0.46 a	28.94 ± 1.89 ab	29.22 ± 2.20 ab
h	70.02 ± 0.85 ab	66.54 ± 2.25 a	72.28 ± 2.07 b	71.06 ± 2.65 b	67.02 ± 1.59 a	68.52± 3.46 ab	68.59 ± 1.88 ab
C	33.43 ± 2.54 b	31.77 ± 1.63 b	30.14 ± 2.33 ab	29.77 ± 3.31 ab	27.89 ± 0.27 a	31.12 ± 1.31 ab	31.40± 2.04 ab

(*) Values in the same row followed by different letters are significantly different.

TPA and crumb firmness test

The average values for hardness, chewiness, cohesiveness, springiness, and crumb firmness of bread produced with different improvers are shown in Table 6. Significant differences were observed mainly for hardness, cohesiveness, springiness, and crumb firmness; therefore, both the type of emulsifier and the enzymatic system played a decisive role in crumb texture development.

In terms of hardness, the DMG90-SSL-M treatment produced significantly softer bread with lower hardness values, followed by DMG90-DATEM-M, whereas DMG90-DATEM-E produced the hardest bread. These results suggest synergistic interaction between emulsifiers and enzyme specificity. According to Tebben et al. (2), SSL improves bread texture primarily by enhancing gas retention during fermentation and early baking, leading to better crumb expansion and reduced hardness. In this study, the combination of SSL with distilled monoglycerides (DMG90) further contributed to crumb softening, likely due to reinforcement of the gluten network and stabilization of gas cells during baking. In terms of crumb firmness, the highest value was observed for the SOYLEC-E treatment, with no significant difference among the other treatments

Monoglycerides are well known for their ability to form complexes with amylose, limiting starch retrogradation and reducing crumb firming during storage (19). This mechanism explains the lower firmness values observed in DMG90-containing formulations, particularly when combined with Enzyme M. Similar effects were reported by Karimi et al. (20), who demonstrated that emulsifiers such as SSL and DATEM combined with amylolytic enzymes significantly reduced bread hardness and delayed crumb firming up to 72 h after baking by stabilizing the starch–protein matrix.

The differences observed between Enzyme M and Enzyme E treatments further emphasize the importance of enzyme composition in texture development. Enzyme M consisted exclusively of maltogenic α-amylases (Alphamalt Fresh 15), which selectively hydrolyze the outer branches of amylopectin and generate low-molecular-weight dextrins that interfere with starch recrystallization.

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This controlled hydrolysis is widely recognized as an effective anti-staling mechanism. It contributes to softer crumbs and reduced firmness without excessively weakening crumb structure (21, 22). Consequently, formulations containing Enzyme M consistently presented lower hardness and crumb firmness values.

In contrast, Enzyme E (Alphase Extra Bake, Eurogerm S.A.S.) is a multi-enzyme preparation composed of maltogenic α-amylases, hemicellulases, lipases, and wheat flour. While such multi-enzyme systems can improve dough handling and loaf volume, their combined activity may also produce more complex structural effects. Hemicellulases can degrade non-starch polysaccharides in the cell wall, improving dough extensibility and gas retention, whereas lipases promote the in-situ formation of surface-active lipids that act similarly to emulsifiers (23). However, the simultaneous action of multiple enzymes may lead to a less controlled modification of the starch–gluten matrix, potentially explaining the higher hardness observed in DMG90-DATEM-E breads. Excessive polysaccharide degradation or lipid restructuring may weaken crumb integrity, resulting in firmer textures after baking.

Chewiness did not differ significantly among treatments, indicating that variations in hardness and springiness were not sufficient to affect the overall energy required for mastication. Regarding cohesiveness, no clear significant difference is observed among the treatments, with values ranging from 0.36 to 0.29. The commercial treatment showed the lowest numerical cohesiveness, while the DMG90-DATEM-M, DMG90-SSL-M, and SOYLEC-M treatments showed the highest, suggesting a more internally bonded and resilient crumb structure. The remaining treatments exhibited intermediate values, reflecting a balance between softness and structural integrity.

The springiness of the product ranges from 0.03 to 0.04, with very similar values across treatments. Soy lecithin enhances dough springiness by strengthening gluten interactions and increasing viscoelastic resistance (7). However, when lecithin is combined with maltogenic α-amylase (M), the reduction in springiness may be due to increased starch modification and a more relaxed crumb structure that favors softness over elastic recovery.

Overall, the DMG90-SSL-M formulation showed the most favorable balance between reduced hardness, adequate cohesiveness, and controlled springiness. The targeted action of maltogenic α-amylase, combined with the stabilizing effects of SSL and monoglycerides, likely contributed to a more stable gluten–starch network and presumably delayed starch retrogradation, resulting in improved crumb texture and freshness. These findings highlight the importance of selecting enzyme systems with controlled activity to maximize texture quality in bread improver formulations.

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Table 6. Textural properties of sliced bread with different improvers, evaluated with the Texture Profile Analysis (TPA) test.

TREATMENT	DMG90-DATEM - E	DMG90-DATEM- M	SOYLEC - M	SOYLEC- E	DMG90-SSL-M	DMG90-SSL - E	COMMERCIAL
Hardness(N)*	13.70 ± 2.09 c*	9.32 ± 1.66 ab	11.04 ± 1.5 abc	12.38 ± 0.91 bc	8.53 ± 1.11 a	10.37± 1.42 abc	12.65 ± 4.07 bc
Chewiness (J)*	0.14 ± 0.02 a	0.12 ± 0.02 a	0.12 ± 0.01 a	0.14 ± 0.02 a	0.11 ± 0.01 a	0.12 ± 0.01 a	0.14 ± 0.04 a
Cohesiveness	0.33 ± 0.03 abc	0.36 ± 0.01 c	0.35 ± 0.02 bc	0.31 ± 0.02 ab	0.36 ± 0.02 bc	0.32 ± 0.05 abc	0.29 ± 0.03 a
Springiness (m)*	0.03 ± 0.00 ab	0.04 ± 0.00 ab	0.03 ± 0.00 a	0.04 ± 0.00 b	0.03 ± 0.00 a	0.03 ± 0.00 ab	0.04 ± 0.00 ab
Crumb firmness (N)*	6.94 ± 1.31 ab	5.43 ± 1.30 a	5.13 ± 0.59 a	8.72 ± 1.14 c	4.59 ± 0.88 a	6.58 ± 1.58 ab	6.90 ± 1.28 ab

(*)Values in the same row followed by different letters are significantly different. Hardness was expressed in newtons (N). Chewiness was expressed in joules (J). Springiness was expressed in meters (m).

TPA and crumb firmness test for the DMG90-SSL-M treatment and the commercial treatment

As evidenced by previous TPA and crumb firmness test results, the DMG90-SSL-M treatment performed best. Hence, TPA and crumb firmness tests were conducted on bread made 6 and 10 days prior to using this treatment, and the results were compared with the commercial treatment at the same times (Table 7). Results indicate that bread formulated with DG90-SSL-M maintained lower hardness values than the commercial treatment at both storage times, reflecting a softer crumb and suggesting better textural stability during storage. This behavior suggests a more effective inhibition of crumb firming during storage, which is commonly associated with starch retrogradation (2). The maltogenic α-amylase was associated with lower crumb firmness and a slower deterioration of texture during storage, suggesting its contribution to maintaining bread softness (24). The lower chewiness values observed for DMG90-SSL-M further support the perception of a more pleasant and less energy-demanding texture during mastication, reinforcing its superior anti-staling performance.

In contrast, bread produced with the commercial improver showed a more pronounced increase in hardness over storage time, indicating a faster loss of freshness. Although Magimix is formulated to enhance dough strength and loaf volume, its long-term crumb softening performance appears less effective than that of the DMG90-SSL-M formulation under the conditions evaluated in this study. Furthermore, cohesiveness and springiness values showed no significant differences between DMG90-SSL-M and the commercial treatment at either storage time, indicating that both formulations were similarly effective in preserving crumb structural integrity and elastic recovery. This suggests that the improved softness observed in DMG90-SSL-M was not achieved at the expense of crumb cohesion or resilience.

Significantly lower crumb firmness values observed in DMG90-SSL-M bread throughout storage demonstrate its enhanced capacity to preserve crumb softness and delay bread hardening

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compared with the commercial improver. The synergistic interaction between SSL, monoglycerides, and maltogenic α-amylase likely contributed to a more stable starch–gluten matrix, resulting in improved crumb softness and the maintenance of bread freshness during storage (22). These results highlight the potential of DMG90-SSL-M as a competitive alternative to commercial bread improvers for applications requiring prolonged softness and textural stability.

Table 7. Textural properties of sliced bread with DMG90-SSL-M improver and commercial improver, evaluated using Texture Profile Analysis (TPA) and crumb firmness testing.

TREATMENT	DMG90-SSL-M		COMMERCIAL	
	6 days	10 days	6 days	10 days
Hardness(N)*	8.02 ± 1.58	9.78 ± 1.58	12.25 ± 1.85	12.41 ± 2.08
Chewiness (J)*	0.11 ± 0.02	0.14 ± 0.02	0.15 ± 0.02	0.16 ± 0.03
Cohesiveness	0.38 ± 0.04	0.37 ± 0.02	0.35 ± 0.02	0.36 ± 0.01
Springiness (m)	0.04 ± 0.00	0.04 ± 0.01	0.04 ± 0.00	0.04 ± 0.00
Crumb firmness (N)*	4.75 ± 0.52	6.15 ± 1.08	7.38 ± 0.59	13.38 ± 1.58

*Crumb firmness and hardness were expressed in newtons (N). Chewiness was expressed in joules (J). Springiness was expressed in meters (m). Values are presented as mean ± standard deviation (n = 7). The measurements at 6 and 10 days are presented for descriptive purposes to illustrate the evolution of bread texture during storage. No statistical comparisons were performed between storage times or treatments.

Conclusions

Results from this research demonstrate that incorporating emulsifiers and enzymes into the formulation of sliced bread can significantly improve its rheological, structural, physical, and sensory properties. In particular, the combination of DMG90 monoglyceride with SSL and M-type enzymes (DMG90-SSL-M treatment) showed the best overall performance, with the longest dough development time, the highest farinographic stability, low mixing tolerance index, and lowest drop-off. Therefore, it yields a stronger dough that is resistant to overmixing and exhibits excellent technological behavior during baking.

In terms of texture, textural profile analysis (TPA) showed that DMG90-SSL-M also produced a softer crumb with lower firmness than the other treatments, resulting in a more tender, higher-quality bread. This improvement can be attributed to the stabilizing effect of the monoglyceride and its synergistic interaction with enzymes, which favors the internal structure and moisture retention. In addition, formulations with soy lecithin (SOYLEC-E and SOYLEC-M) were found to

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have more homogeneous porosity, a higher proportion of small pores, and a lighter crumb color, characteristics that consumers appreciate in bakery products.

The DMG90-SSL-M treatment shows a clear advantage over the commercial treatment, maintaining a softer crumb with lower hardness, chewiness, and firmness throughout storage. This suggests that this treatment helps prolong bread freshness and delay hardening without significantly altering the crumb's cohesiveness or springiness.

Although not all variables showed statistically significant differences, the trends observed support the effectiveness of the improvers used, especially when applied in specific combinations. Taken together, these findings indicate that the use of emulsifiers and enzymes not only represents a viable functional alternative to commercial improvers but can also enhance the technological and sensory quality of sliced bread, with practical applications in today's baking industry.

Practical Applications

This study's results provide practical guidance for formulating bread improvers that enhance crumb softness, dough stability, and shelf life in industrial sliced bread production. A combination of Distilled Monoglycerides (DMG90), Sodium Stearoyl Lactylate (SSL), and maltogenic α-amylase was more effective than a commercial improver at maintaining crumb softness and delaying firming during storage. These findings offer bakery manufacturers an alternative formulation strategy to improve product freshness without altering moisture content or specific volume. The study also clarifies how single-enzyme systems differ from multi-enzyme blends in their impact on dough rheology and texture. This information supports more targeted ingredient selection. Ultimately, this research contributes to the optimization of industrial bread quality, reduction of staling-related losses, and improvement of consumer acceptability by promoting better texture retention over time.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Ethical Statements

The authors declare that this research was conducted in accordance with the principles of scientific integrity, academic responsibility, and compliance with current institutional regulations. This study did not involve experimentation on humans or animals.

Statement of authorship contribution credits

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References

(1) Chowdhury MAH, Sarkar F, Reem CSA, Rahman, SM, Mahamud, AGMSU, Rahman MA, Ashrafudoulla M. Enzyme applications in baking: From dough development to shelf-life extension. Int. J. Biol. Macromol. 2024; 282: 137020.

https://doi.org/10.1016/j.ijbiomac.2024.137020

(2) Tebben L, Chen G, Tilley M, Li Y. Improvement of whole wheat dough and bread properties by emulsifiers. Grain Oil Sci Technol. 2022; 5(2): 59-69.

https://doi.org/10.1016/j.gaost.2022.05.001

(3) Baiano A, Fiore A. Consequences of the addition of bread making improvers to strong flour-based formulations. Pol. J. Food Nutr. Sci. 2026; 76(1): 5-17.

https://doi.org/10.31883/pjfns/215473

(4) Gomez AV, Buchner D, Tadini CC, Añón MC, Puppo MC. Emulsifiers: Effects on quality of fibre-enriched wheat bread. Food Bioprocess Technol. 2013; 6:1228–1239.

https://doi.org/10.1007/s11947-011-0772-7

(5) Eduardo M, Svanberg U, Ahrné L. Effect of hydrocolloids and emulsifiers on baking quality of composite cassava-maize-wheat breads. Int. J. Food Sci. 2014; 2014(1): 479630.

https://doi.org/10.1155/2014/479630

(6) Valsalan A, Swaminathan I, Kadam A, Koksel F, Malalgoda M. Enhancing the breadmaking quality of ancient grains through synergistic emulsifier treatment and extrusion processing. J. Food Sci. 2025; 90(4): e70206.

https://doi.org/10.1111/1750-3841.70206

(7) Cao Y, Jiang L, Suo W, Deng Y, Zhang M, Dong S, Li H. Influence of emulsifiers and enzymes on dough rheological properties and quality characteristics of steamed bread enriched with potato pulp. Food Chem. 2021; 360: 130015.

https://doi.org/10.1016/j.foodchem.2021.130015

(8) AACC. Approved Methods of Analysis, 11th ed. American Association of Cereal Chemists. St Paul. MN. USA: Cereals and Grains Association; 2000. https://www.cerealsgrains.org/resources/Methods/Pages/default.aspx

(9) Rodriguez-Sandoval E, Prasca-Sierra I, Hernandez V. Effect of modified cassava starch as a fat replacer on the texture and quality characteristics of muffins. J. Food Meas. Charact. 2017; 11(4): 1630-1639.

https://doi.org/10.1007/s11694-017-9543-0

(10) Zapata F, Zapata E, Rodriguez-Sandoval E. Influence of guar gum on the baking quality of gluten-free cheese bread made using frozen and chilled dough. Int. J. Food Sci. 2019; 54(2): 313-324.

doi: 10.25100/iyc.v28i2.15820

https://doi.org/10.1111/ijfs.13936

(11) Goswami D, Gupta RK, Mridula D, Sharma M, Tyagi SK. Barnyard millet-based muffins: Physical, textural and sensory properties, LWT - Food Sci Technol. 2015; 64 (1): 374-380.

https://doi.org/10.1016/j.lwt.2015.05.060

(12) Kumar AK, Sharma GK. Functionality of different surfactants on the rheological and micro-structural characteristics of multigrain premix incorporated wheat flour. J Texture Stud. 2017; 48(1): 57-65.

https://doi.org/10.1111/jtxs.12209

(13) AbuDujayn AA, Mohamed AA, Alamri MS, Hussain S, Ibraheem MA, Qasem AAA, Shamlan G, Alqahtani NK. Relationship between dough properties and baking performance of panned bread: the function of maltodextrins and natural gums. Molecules. 2023; 28(1): 1.

https:// doi.org/10.3390/molecules28010001

(14) Vásquez-Lara F, Verdú-Amat S, Islas-Rubio AR, Barat-Baviera JM, Grau-Meló R, Granados-Nevárez MDC, Ramírez-Wong B. Effect of heat treatment on oat flour used as a substitute for wheat flour in bread making. Biotecnia. 2021; 23(2): 55-64.

https://doi.org/10.18633/biotecnia.v23i2.1388

(15) Ahmed IBH, Hannachi A, Haros CM. Combined effect of chia flour and soy lecithin incorporation on nutritional and technological quality of fresh bread and during staling. Foods. 2020; 9(4): 446.

https://doi.org/10.3390/foods9040446

(16) Lopez-Tenorio JA, Rodriguez-Sandoval E, Sepúlveda-Valencia JU. (2015). The influence of different emulsifiers on the physical and textural characteristics of gluten-free cheese bread. J Texture Stud. 2015; 46(4): 227-239.

https://doi.org/10.1111/jtxs.12121

(17) Codină GG, Mironeasa S. The effect of lecithin on alveograph characteristics, baking and sensorial qualities of wheat flour. Food Environ Saf. 2016; 12.

https://fens.usv.ro/index.php/FENS/article/view/140

(18) Yeşil S, Levent H. The effects of emulsifiers on quality and staling characteristics of gluten-free bread containing fermented buckwheat, quinoa, and amaranth. J Food Process Preserv. 2022; 46(7): e16668.

https://doi.org/10.1111/jfpp.16668

(19) Xu Q, Sang S, Wang Y, Tan CP, Peplowski L, Tang X, Meng M, Lei H. Effect of glycerol monostearate on the structure and retrogradation of gelatinized wheat starch at high temperature. Grain Oil Sci Technol. 2025; 8 (2025): 175-181.

https://doi.org/10.1016/j.gaost.2025.05.003

(20) Karimi M, Sheikholeslami Z, Ghiafehdavoodi M, Ghods-Rohani M. Investigating the effect of emulsifiers and enzymes on the physicochemical and organoleptic characteristics of flat bread fermented by direct and sponge method. J Food Bioprocess Eng. 2023; 6(1), 18-25.

https://doi.org/10.22059/jfabe.2023.352000.1134

(21) Chen Y, Severin E, Schubert S, Gorgerat S, Boschet E, Baltensperger L, Stadeli C, Kuster S, Fischer P, Windhab E. Influence of amylase addition on bread quality and bread staling. Food Sci Technol. 2021; 6: 1143-1150.

https://doi.org/10.1021/acsfoodscitech.1c00158

(22) Liu P, Ma L, Duan W, Gao W, Fang Y, Guo L, Yuan C, Wu Z, Cui B. Maltogenic amylase: Its structure, molecular modification, and effects on starch and starch-based products. Carbohydr Polym. 2023; 319: 121183.

https://doi.org/10.1016/j.carbpol.2023.121183

(23) Stemler CD, Scherf KA. Improvement of cake baking properties by lipases compared to a traditional emulsifier. Food Chem: X. 2022; 15: 100442.

https://doi.org/10.1016/j.fochx.2022.100442

(24) Haghighat-Kharazi S, Kasaai MR, Milani JM, Khajeh K. (2020). Optimization of encapsulation of maltogenic amylase into a mixture of maltodextrin and beeswax and its application in gluten-free bread. J Texture Stud. 2020; 51(4): 631-641.

https://doi.org/10.1111/jtxs.12516

doi: 10.25100/iyc.v28i2.15820