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EVALUATION OF THE BEHAVIOUR OF BAKER'S YEAST IN FROZEN DOUGH UNDER VARYING FREEZING-THAWING AND STORAGE PARAMETERS

Ioana ISACHE[1]
[1]*Faculty of Food Engineering, Stefan cel Mare University of Suceava, Romania*
*Corresponding author: ioana.isache1@gmail.com
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Abstract: *This study systematically evaluates the influence of freezing–thawing regimes and storage duration on the fermentative performance of baker's yeast and the quality attributes of bakery products obtained from frozen dough. Dough samples were subjected to rapid freezing to thermal centre temperatures of −5 °C, −10 °C, and −15 °C, followed by storage at −18 °C for up to 56 days and subsequent application of controlled thawing protocols. Yeast activity was quantified based on CO_2 production after 60 and 120 minutes of fermentation, while product quality was assessed through specific volume, textural parameters, and sensory evaluation using a 9-point hedonic scale. The results demonstrate that decreasing the final freezing temperature significantly enhances yeast viability and preserves functional performance during storage. Samples frozen to −15 °C consistently exhibited superior fermentative capacity, improved structural characteristics, and higher sensory acceptability. A progressive decline in yeast activity and product quality was observed with increasing storage time, reaching reductions of approximately 30% after 56 days. Statistical analysis revealed strong positive correlations (r = 0.927–0.990) between fermentative activity and overall acceptability, confirming the central role of yeast metabolic performance in determining final product quality. These findings provide robust evidence that the optimization of freezing and thawing parameters represents a critical factor in maintaining the technological functionality of yeast and ensuring the quality stability of frozen dough-based bakery products.*

Keywords: *dough fermentation, cryoprotection, thermal processing, gas production, bakery quality, texture analysis, storage stability, sensory evaluation*

1. Introduction

Yeast is an essential microorganism in the baking industry, playing a fundamental role in the development of the structure and sensory properties of bakery products. The quality of finished products largely depends on the characteristics of the raw materials and ingredients used in the technological process, such as flour, yeast, water, and various functional ingredients or baking improvers. In this context, yeast plays a central role in the fermentative processes that determine dough expansion and the development of the final product structure [1]. The use of yeasts in bread production has been known since ancient times; however, modern studies have highlighted the complexity of the biochemical processes involved in dough fermentation and the diversity of yeast species that may participate in these processes [2,3]. Among these, *Saccharomyces cerevisiae* is the microorganism most frequently used in the baking industry due to its high fermentation capacity, technological stability, and the production of aromatic compounds that contribute to the final quality of bakery products [4,5]. During fermentation, yeast metabolizes fermentable sugars present in the dough, generating carbon dioxide and ethanol. The carbon dioxide produced is retained within the gluten network of the dough, leading to an increase in dough volume and the formation of a porous structure characteristic of bakery products. In addition to the main fermentation

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products, yeast synthesizes a series of secondary metabolites, such as higher alcohols, esters, organic acids, and carbonyl compounds, which significantly contribute to the aroma and flavour of bakery products [6,7]. The metabolic activity of yeast is influenced by numerous factors, including dough composition, the rheological properties of flour, fermentation conditions, and the interactions between the structural components of the dough [8]. The structure of bread dough is mainly determined by the interactions between gluten proteins and starch granules, which form a viscoelastic matrix capable of retaining the gases produced during fermentation. The properties of this protein network can be influenced by various technological factors, such as redox agents, enzymes, or emulsifiers used in the baking process. The use of redox agents and exogenous enzymes may modify the structure of the protein network and influence the extensibility and stability of dough during processing [9]. Furthermore, the activity of amylolytic enzymes plays an important role in starch degradation and in providing fermentable sugars necessary for yeast metabolism [10]. In recent decades, frozen dough technology has experienced significant development in the baking industry due to the economic and logistical advantages it offers, such as production flexibility, distribution optimization, and extended shelf life of products [11,12].

However, the freezing process can cause structural and biochemical changes in the dough, affecting both the viability of yeast cells and the integrity of the gluten network [13]. The formation of ice crystals during freezing may cause damage to yeast cell membranes and modifications in protein structure, which leads to reduced fermentation capacity and decreased volume of bakery products obtained from frozen dough. During frozen storage, the quality of frozen dough gradually decreases, which is closely related to the formation and changes of the dough network [14]. Dough is composed of various components, including water, gluten, and starch. The dough production process involves mixing wheat flour with water to form gluten, which interacts with itself to form a three-dimensional network [15]. Through this structure, the dough retains water and has a viscoelastic structure. During storage with temperature fluctuations, dough-based foods can suffer serious quality problems due to ice crystal growth and recrystallization. It has been found that frozen dough loses water after freezing and thawing, and that large ice crystals in the dough destroy the internal structure, leading to the separation of starch granules and protein network structure [16]. Furthermore, the water distribution and microstructure of frozen dough can be modified by multiple freeze-thaw cycles, for example, promoting ice recrystallization, disrupting the interaction between dough components and water molecules, and depolymerizing the high molecular weight gluten portion [17]. Flour properties and gluten quality significantly influence the behaviour of dough during freezing and storage processes. Flours with higher gluten content and appropriate rheological properties show better stability of the protein network and a greater capacity to retain the gases produced during fermentation [18].

At the same time, the addition of vital wheat gluten can improve the structure of frozen dough and contribute to maintaining the volume and texture of baked products [19]. To reduce the negative effects of the freezing process on dough quality, the baking industry frequently uses improvers, enzymes, and emulsifiers that contribute to stabilizing dough structure and improving technological properties. Surfactants and emulsifiers can improve the interactions between gluten proteins and starch, contributing to the maintenance of the structural stability of frozen dough [20,21].

In addition, the use of specific enzymes, such as lipases or amylases, can improve the rheological properties of dough and help maintain the texture of bakery products obtained from frozen dough [22, 23, 24]. The application of enzymatic treatments represents another strategy used to reduce structural deterioration of dough during freezing. Studies have shown that the use of appropriate enzymes can reduce protein network degradation and contribute to maintaining the quality of bakery products obtained from frozen dough [25]. In addition, certain functional ingredients, such as ascorbic acid or glycerol, may improve the structural stability of dough and reduce the negative effects of the freezing process on the physical properties of final products [26]. In recent years, research has also highlighted the importance of using cryoprotective agents to protect yeast cells during freezing and storage processes. These compounds may contribute to maintaining cell membrane integrity and to reducing the effects of thermal stress on microorganisms involved in fermentation [27].

Considering the importance of frozen dough technology in the baking industry and the significant impact of technological parameters on yeast activity and on the quality of final products, the present study aimed to evaluate the influence of variations in freezing–thawing parameters and storage duration on the fermentative activity of yeast and on the physical and sensory characteristics of buns obtained from frozen dough.

The study synthesizes my own research on the study of the behaviour of baker's yeast in frozen bun dough obtained under different freezing and thawing conditions, over a period of 8 weeks of storage under the same conditions. For the relevance of the study, the activity of baker's yeast, as well as the organoleptic and physical qualities of the finished product, were analysed at each thawing period.

2. Materials and methods

2.1. Materials

For the 300 g bun dough samples, obtained according to the manufacturing recipe presented in Table 1, the following ingredients were used: white wheat flour 650 sold by SC SAPTE SPICE SA (Iași, Romania); compressed baker's yeast, manufacturer SC ROMPAK SRL (Pașcani, Romania); recrystallized extra fine salt, iodized, manufacturer Ginavidor (Galați, Romania) with a sodium chloride content of 99.5%; Eka Excel Fresh bread improver, which contains enzymes (fungal alpha-amylase, fungal xylanase, bacterial xylanase and lipase) and ascorbic acid produced and sold by SC ROMPAK SRL. (Pașcani, Romania); drinking water, from the network, with a hardness of 22 °dH (ISO 6059); commercial ice cubes. The dough buns recipe is described in Table no. 1.

The wheat flour used was analyzed in accordance with Romanian and international standard methods, according to the International Association for Cereal Science and Technology – ICC, and presented the following characteristics: moisture: 14.1% (SR EN ISO 712:2010); ash: 0.65% (ICC 104/1/1990); wet gluten: 29.2% (SR 90:2007); falling number: 416.5 s (SR EN ISO 3093:2010), deformation index: 2 mm (SR 90:2007). Baker's yeast was analyzed according to Romanian and international standard methods, having the following characteristics: dry matter 33.34%, protein content in dry matter (N x 6.25) 43.375%, fermentative activity after 60 minutes, 799 mL CO_2, fermentative activity after 120 minutes, 920 mL CO_2, trehalose content 18.6%.

2.2. Technological process

2.2.1. Dough preparation

The raw materials were weighed, dosed into the spiral mixer Esmach NSE 30 (Bongard Group, France), and kneaded for five minutes at low speed and another five minutes at high speed of the mixer. At the end of the kneading stage, the temperature

of the dough was measured, taking care that it was between 19-20 °C. No variations in water/ice quantities were necessary to obtain the dough temperature within the desired temperature range. The dough thus prepared was divided into 56 pieces of 72 g of dough each. The dough pieces were manually shaped into round shapes.

Table 1.

Dough buns recipe

No. Crt.	Name of the ingredients	U.M.	Qty. for 1000 g of dough
1.	White wheat flour 650	g	661,5
2.	Yeast	g	17,6
3.	Iodized salt	g	8,8
4.	Eka Excel Fresh bread improver	g	8,8
5.	Water	mL	220,5
6.	Ice	g	82,8

2.2.2. Sample freezing method

The freezing of the dough samples and buns was conducted in a shock freezer (EVCO Group Thermal, Italy), with a capacity of four trays, at a temperature of -35 °C.

The freezing duration varies depending on the temperature in the thermal center at the end of quick freezing (-5 °C, -10 °C, -15 °C), ranging between 45 and 70 minutes for buns.

The temperature in the thermal center of the buns was continuously measured, using the temperature measurement probe provided in the shock freezer, until the desired temperature was reached. In this way, the necessary freezing time of the samples was established.

2.2.3. Sample storage

The storage of frozen dough samples and frozen finished products was conducted in a cold room (Cryocabin EF1216VT01), at a temperature of -18 °C, for a period of eight weeks. The samples were analyzed over a period of 56 days. The analyses were performed after 7, 14, 28, 42, and 56 days of storage, respectively.

2.2.4. Thawing of samples

The thawing of dough samples and finished products was carried out in a refrigerator set at 8 °C for 30, 60, and 90 minutes. Subsequently, samples were tempered at ambient temperature (22 °C) for 90, 60, and 30 minutes, respectively, to ensure comparable total thawing time.

Table 2.

Technological parameters used in freezing and thawing products, after storing frozen samples at -18 °C

Sample	Freezing temperature, [°C]	Time, [min.]:		
		freezing	defrost at 8 °C	defrost at 22 °C
A_1	-5	45	30	90
A_2			60	60
A_3			90	30
B_1	-10	55	30	90
B_2			60	60
B_3			90	30
C_1	-15	70	30	90
C_2			60	60
C_3			90	30

2.2.5. Fermentation of samples

The fermentation of the buns was conducted in the proofer (Miwe, Germany), whose temperature was set at 35 °C and humidity at 75%, for 50 minutes.

2.2.6. Baking samples

The baking of the buns was conducted in the Aero oven (Miwe, Germany), with convection, with ventilation set to level 4, at a temperature of 230 °C, for 10 minutes, with 120 mL of steam at the beginning of baking.

2.3. Analysis methods

2.3.1. Determination of baker's yeast activity in dough

Yeast fermentative activity was determined using a Y55 Gastograph (Yucebas Machinery Analytical Equipment Industry, Turkey), based on the measurement of carbon dioxide (CO_2) production during dough fermentation under controlled conditions. Dough samples were prepared according to a standardized formulation identical to that used in the experimental design. The samples were subjected to the same freezing conditions as the bun dough to ensure the comparability of results.

The prepared dough was introduced into the Gastograph chamber, where fermentation was carried out under controlled temperature and humidity conditions.

The volume of CO_2 released during fermentation was continuously recorded over a period of 120 minutes. Fermentative activity was expressed as the cumulative volume of CO_2 (mL) produced after 60 and 120 minutes, respectively, and corrected to standard atmospheric pressure.

This method allows the evaluation of yeast metabolic capacity and provides a quantitative indicator of its ability to generate fermentation gases, which are essential for dough development and final product quality.

Fig. 1. Gastograf Y55 Yucebas Machinery

2.3.2. Determination of the quality characteristics of the finished product buns

For each test, seven bun samples were analyzed from both physical and sensory perspectives. The physical characteristics (specific volume, porosity, and elasticity) were determined in accordance with the Romanian standard SR 91:2007. The TexVol Instrument BVM device was used to determine the specific volume.

Textural properties were determined using a CT3 Texture Analyzer (Brookfield Corporation, Canada). Hardness was measured as the maximum force required to compress the sample, expressed in grams. The analysis was performed using a single compression cycle to 20% of the initial sample height, with a cylindrical probe (45 mm diameter), at a test speed of 2.0 mm/s and a trigger force of 5 g. Hardness is determined by measuring the maximum

force required to compress a sample, expressed in grams. Sensory analysis was performed using a 9-point hedonic scale (where 1 indicates you dislike it very much and 9 indicates you like it very much) with a panel of 10 semi-trained raters. The following sensory characteristics of the bread were evaluated: appearance, aroma, taste, color, texture, smell, and overall acceptability.

3. Results and discussion

3.1. Influence of variations in freezing thawing parameters and storage time on yeast activity

The selection of freezing–thawing parameters was based on data reported in the literature regarding frozen dough stability and yeast performance, including studies by Selomulyo & Zhou [10], Meziani et al. [12], and Luo et al. [15], which highlight the influence of freezing rate, storage conditions, and thawing regimes on yeast viability and dough structure. These sources provided the scientific basis for choosing the freezing–thawing parameters described in Section 2 (Materials and methods). For the determination of fermentative activity, dough samples of 300 g were prepared separately according to the standardized method required by the Gastograph. These samples were not shaped into buns but maintained as bulk dough to ensure proper measurement conditions. The freezing of these samples followed the same thermal profiles (−5 °C, −10 °C, −15 °C in the thermal centre) as applied to the bun dough, ensuring comparability between fermentative activity measurements and the technological process. The results of the Gastograph analysis of the fermentative activity of baker's yeast are summarized in tables 3 and 4, which were:

A_1 – buns dough frozen for 45 minutes to a temperature of -5 °C, stored at -18 °C, and thawed in the refrigerator, at a temperature of 8 °C, for 0 minutes and a further 90 minutes at a temperature of 22 °C

A_2 – buns dough frozen for 45 minutes to a temperature of -5 °C, stored at -18 °C, and thawed in the refrigerator, at a temperature of 8 °C, for 60 minutes and a further 60 minutes at a temperature of 22 °C

A_3 - buns dough frozen for 45 minutes to a temperature of -5 °C, stored at -18 °C and thawed in the refrigerator, at a temperature of 8 °C, for 90 minutes and a further 30 minutes at a temperature of 22 °C

B_1 - buns dough frozen for 45 minutes to a temperature of -10 °C, stored at -18 °C, and thawed in the refrigerator at a temperature of 8 °C for 0 minutes and another 90 minutes at a temperature of 22 °C

B_2 - buns dough frozen for 45 minutes to a temperature of -10 °C, stored at -18 °C, and thawed in the refrigerator at a temperature of 8 °C for 60 minutes and another 60 minutes at a temperature of 22 °C

B_3 - buns dough frozen for 45 minutes to a temperature of -10 °C, stored at -18 °C, and thawed in the refrigerator at a temperature of 8 °C for 90 minutes and another 30 minutes at a temperature of 22 °C

C_1 - buns dough frozen for 45 minutes to a temperature of -15 °C, stored at -18 °C, and thawed in the refrigerator at a temperature of 8 °C for 0 minutes and another 90 minutes at 22 °C

C_2 - buns dough frozen for 45 minutes to -15 °C, stored at -18 °C and thawed in the refrigerator at 8 °C for 60 minutes and another 60 minutes at 22 °C

C_3 - buns dough frozen for 45 minutes to -15 °C, stored at -18 °C and thawed in the refrigerator at 8 °C for 90 minutes and another 30 minutes at 22 °C.

3.2. Influence of variations in freezing thawing parameters and storage time on the physical characteristics of the finished product buns

After freezing, storage, and thawing, the dough pieces (previously shaped before freezing, with a weight of 72 g each, as described in Section 2) were directly subjected to fermentation and baking. No reshaping was performed after thawing, to

Table 3.
Yeast fermentative activity, after 60 minutes of analysis, in frozen bun dough during storage (mL CO_2)

Frozen dough sample	Storage time of frozen dough, [days]							
	7	**14**	**21**	**28**	**35**	**42**	**49**	**56**
A_1	520	515	480	430	405	392	380	350
A_2	530	528	492	440	415	400	390	361
A_3	551	543	504	455	432	425	419	381
B_1	561	552	514	460	435	419	409	399
B_2	572	558	519	462	441	420	414	402
B_3	580	580	536	468	449	438	421	401
C_1	586	581	540	478	450	439	435	405
C_2	586	586	548	481	451	441	439	409
C_3	616	610	558	505	489	479	461	421

Table 4.
Yeast fermentative activity, after 120 minutes of analysis, in frozen bun dough during storage (mL CO_2)

Frozen dough sample	Storage time of frozen dough, [days]							
	7	**14**	**21**	**28**	**35**	**42**	**49**	**56**
A_1	720	715	640	611	583	555	542	522
A_2	725	721	655	620	591	563	548	523
A_3	760	755	670	641	616	581	562	528
B_1	789	780	690	662	632	601	583	532
B_2	795	790	700	670	633	609	590	540
B_3	801	800	705	681	645	618	601	561
C_1	811	810	710	688	651	628	605	588
C_2	821	816	715	699	660	625	615	595
C_3	831	829	729	700	681	651	631	601

maintain consistency with the technological process. After baking, the samples were allowed to cool at room temperature (22 °C) for 2 hours before analysis, to ensure stabilization of internal structure and temperature. The specific volume and texture of each finished product sample were analyzed. The results of the two determinations are summarized in Figures no. 5 and 6. Freezing time significantly influences the hardness of the core. The highest values, corresponding to a firmer texture, are found especially in samples frozen for 45 minutes, to -5 °C in the thermal center, which suggests that a less deep freezing leads to a denser internal structure, a phenomenon that can be associated with the formation of larger ice crystals, which damage the gluten matrix and reduce the re-expansion capacity of the core. A longer freezing time, 70 minutes, to -15 °C, in the thermal center of the buns has a favorable effect on maintaining a less firm texture. The measured hardness values, in this case, are significantly lower, indicating a more aerated texture, similar to that of fresh products.

3.3. Influence of variations in freezing thawing parameters and storage time on the sensory characteristics of buns

The optimal variant for maintaining sensory quality is represented by long-term freezing (70 minutes) to a temperature of −15 °C in the thermal centre of the buns, combined

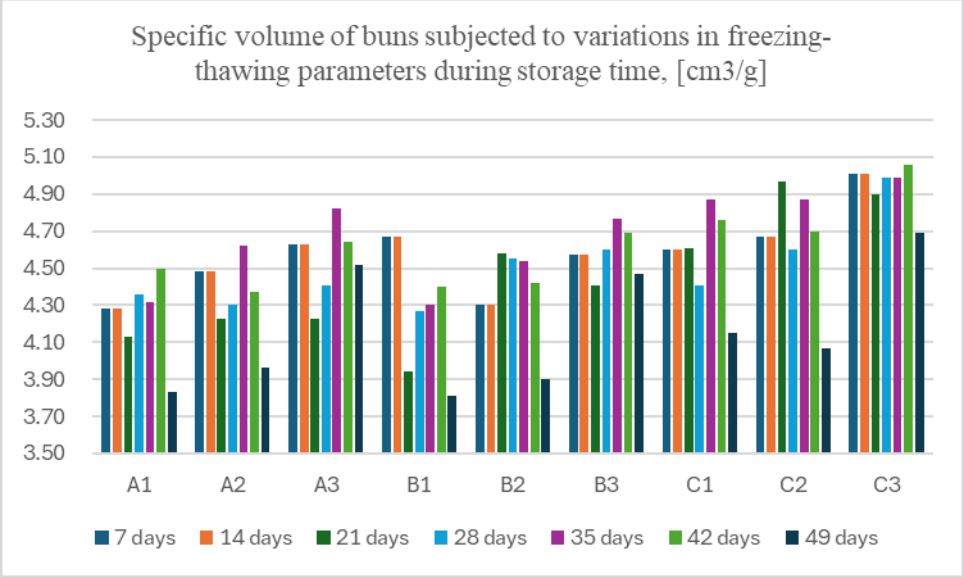

Fig. 2. Specific volume of buns subjected to variations in freezing-thawing parameters during storage time, [cm^3/g]

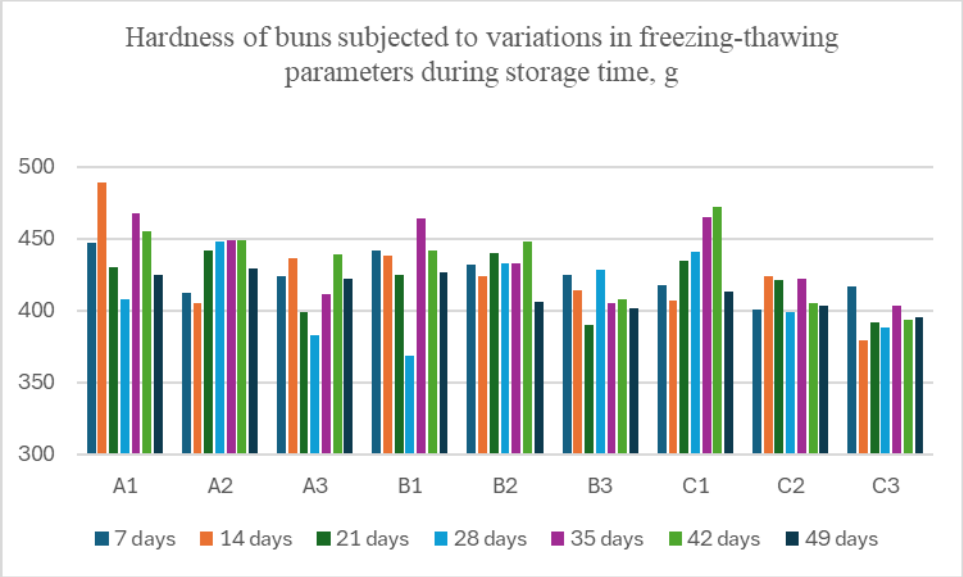

Fig. 3. Hardness of buns subjected to variations in freezing-thawing parameters during storage time, g

with a two-stage thawing process of 90 minutes at 8 °C followed by 30 minutes at 22 °C (sample C3). This variant consistently provides the highest scores for the sensory properties of the buns.

Overall acceptability is significantly influenced by the final temperature reached in the thermal center during freezing, the values systematically increasing as the final temperature, after quick freezing, decreases from -5 °C to -15 °C.

Throughout the storage period at -18 °C, buns frozen for 70 minutes to -15 °C in the thermal center (Samples C_1, C_2, C_3) obtained the highest scores on overall acceptability, which indicates a superior maintenance of sensory properties (taste, aroma, smell, texture).

The defrosting method directly influences the metabolic capacity of yeast, most likely through its effect on cell membrane integrity and on the rate of metabolic reactivation after freezing. The method applied to the A_3, B_3, and C_3 samples allows a higher fermentative activity to be maintained, with aproximately 4% higher compared with A_2, B_2, and C_2, and 4% higher compared with A_1, B_1, and C_1, indicating a more favorable adaptation of yeast cells during the resumption of fermentation. The best results generally occur with two-stage thawing, 30 minutes at 8 °C and 90 minutes at 22 °C, suggesting that a slow thermal transition limits moisture losses.

The samples analyzed in the last weeks of storage predictably show lower values compared to the samples analyzed in the first three weeks, but even in these cases, freezing for 70 minutes, to a temperature of -15 °C, in the thermal center of the buns, allows maintaining acceptable scores, which confirms the relatively good stability of the product under storage conditions.

The appearance of the finished product is the most sensitive parameter to freezing conditions, with samples A_1, A_2, A_3 having lower values compared to samples B_1, B_2, B_3, respectively, C_1, C_2, C_3. This is explained by the appearance of microcracks and volume losses caused by larger ice crystals.

The optimal variant for maintaining sensory quality is represented by long-term freezing, 70 minutes, to a temperature of -15 °C in the thermal center of the buns and thawing in two stages, for 30 minutes at a temperature of 8 °C and for 90 minutes at a temperature of 22 °C. This variant consistently provides the highest scores on the sensory properties of the buns. The results obtained on the yeast fermentation activity show a direct correlation with the physical properties of the buns, in particular with the specific volume and the texture of the core. The samples that recorded higher values of CO_2 production during the gastograph analysis, especially those frozen to a temperature of −15 °C in the thermal center (C_1, C_2, C_3), also consistently showed higher values of the specific volume. This confirms the essential role of yeast metabolic activity in the generation of fermentation gases, which cause dough expansion and the formation of a uniform porous structure.

As the storage time of frozen dough increases, the gradual decrease in yeast activity leads to a reduction in the amount of CO_2 produced during fermentation, which is reflected in lower values of the specific volume and a denser internal structure of the product. At the same time, this reduction in fermentative capacity is associated with an increase in core firmness, a phenomenon highlighted by the higher values of textural parameters recorded in samples with lower fermentative activity.

Therefore, freezing and thawing parameters simultaneously influence yeast viability, gas production capacity, and structural properties of bakery products, demonstrating that maintaining high fermentative activity is essential for obtaining buns with adequate volume, aerated texture, and sensory characteristics close to those of fresh products. The results of the sensory analysis are summarized in Table 4 and graphically represented in Figure 4.

The comparison of the sensory profiles highlights higher acceptability values for samples from series C, followed by samples from series B, while samples from series A present the lowest sensory scores. The general trend indicates a gradual decrease in acceptability as the storage time increases.

Table 5.

Summary of results regarding the overall acceptability of buns – finished product

Frozen dough sample	Storage time of frozen dough, [days]						
	7	**14**	**21**	**28**	**35**	**42**	**49**
A_1	7,1	7,0	6,9	6,8	6,7	6,6	6,5
A_2	7,3	7,2	7,1	7,0	6,9	6,8	6,7
A_3	7,4	7,3	7,2	7,1	7,0	6,9	6,8
B_1	7,5	7,4	7,3	7,2	7,1	7,0	6,9
B_2	7,6	7,6	7,4	7,3	7,2	7,1	7,0
B_3	7,8	7,7	7,6	7,5	7,3	7,3	7,2
C_1	7,9	7,8	7,7	7,6	7,5	7,4	7,4
C_2	8,2	8,0	8,0	7,9	7,8	7,7	7,7
C_3	8,4	8,3	8,2	8,0	8,0	7,8	7,7

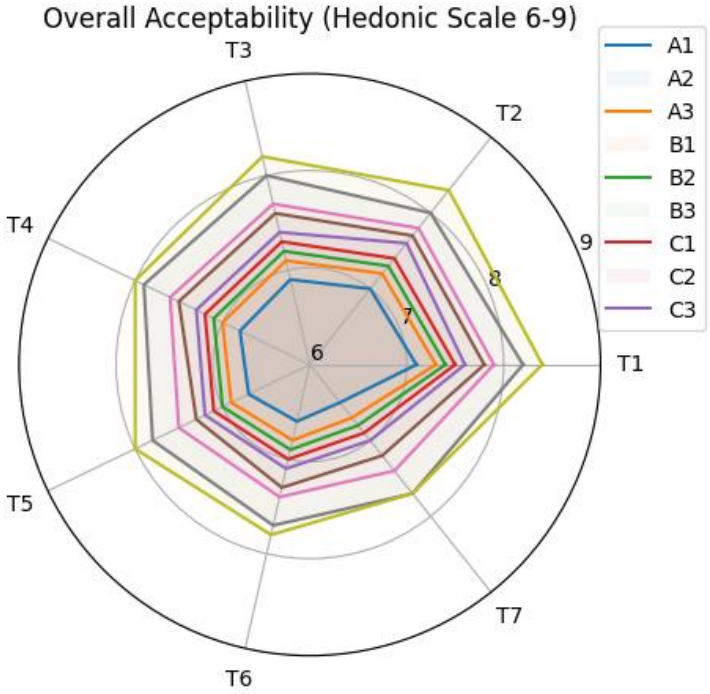

Fig. 4. Evolution of the sensory profile of the finished product during storage

3.4. Relationship between yeast fermentative activity and overall acceptability

To evaluate the relationship between yeast fermentative activity and the sensory quality of buns obtained from frozen dough, Pearson correlation coefficients (r) and linear regression analysis were applied using the experimental data obtained during the frozen storage period. The results revealed a very strong positive correlation between yeast activity (expressed as CO_2 production after 120 minutes) and overall acceptability scores for all analysed samples. The Pearson correlation coefficients ranged between 0.927 and 0.990, indicating a highly consistent relationship between the two variables. All correlations were found to be statistically significant ($p < 0.01$), confirming that the observed relationships are not due to random variation. The coefficients of determination (R^2) varied between 0.860 and 0.980, demonstrating that up to 98% of

the variation in sensory acceptability can be explained by the variation in yeast fermentative activity. Among the analysed samples, B2 exhibited the strongest correlation ($r = 0.990$, $R^2 = 0.980$), followed by A2 and A3, while sample C2 showed the lowest, yet still very strong correlation ($r = 0.927$, $R^2 = 0.860$). This slight variation may be attributed to the influence of additional quality parameters such as texture and aroma, which become more relevant at higher levels of product quality.

The regression analysis confirmed a direct linear relationship, indicating that increases in CO_2 production are associated with proportional increases in sensory acceptability. This relationship highlights the fundamental role of yeast metabolic activity in determining the final quality of bakery products. During frozen storage, the progressive decrease in yeast fermentative activity was directly associated with a decline in overall acceptability. This behaviour can be explained by the reduced capacity of yeast to produce carbon dioxide, leading to lower dough expansion, decreased specific volume, and a denser crumb structure, ultimately affecting consumer perception. These findings are consistent with the observed experimental trends, where samples from group C (frozen to −15 °C) maintained higher fermentative activity and, consequently, superior sensory scores throughout the storage period. In contrast, samples from group A exhibited lower yeast activity and reduced acceptability.

Overall, the results demonstrate that yeast fermentative activity is a key predictor of sensory quality in frozen dough products and represents a critical parameter for optimizing freezing and storage technologies in the bakery industry.

Table 6.

Correlation and regression parameters describing the relationship between CO_2 production and sensory acceptability during frozen storage

Sample	r (Pearson)	*p*-value	R^2
A_1	0.976	0.00016	0.953
A_2	0.982	0.00008	0.964
A_3	0.977	0.00015	0.955
B_1	0.975	0.00019	0.950
B_2	0.990	0.00002	0.980
B_3	0.967	0.00036	0.936
C_1	0.974	0.00022	0.948
C_2	0.927	0.00263	0.860
C_3	0.956	0.00078	0.913

Pearson correlation coefficients (r), significance levels (*p*-value), and coefficients of determination (R^2) describing the relationship between yeast fermentative activity and overall acceptability for each sample.

4. Conclusions

The results of the study highlight the significant influence of freezing conditions on yeast activity and on the sensory quality of bakery products during storage. Determination of yeast fermentative activity after 60 and 120 minutes demonstrated that freezing parameters can affect the viability and metabolic capacity of yeast cells, an essential aspect for the optimal development of the fermentation process and for obtaining products with appropriate volume and structure. Sensory analysis, performed based on the 9-point hedonic scale, highlighted differences between the three groups of samples analyzed. Samples in group C recorded the highest global acceptability scores

throughout the entire storage period, indicating superior sensory stability. Samples in group B presented intermediate values, while samples in group A recorded the lowest sensory scores. Also, a tendency of gradual decrease in product acceptability was observed with increasing storage time. Overall, the results obtained demonstrate that optimizing freeze-thaw conditions contributes to maintaining yeast activity and preserving the sensory characteristics of bakery products. These results may constitute an important basis for improving freeze-thaw technologies applied in the bakery industry.

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