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VISCOELASTIC CHARACTERISTICS OF PART-BAKED BREAD UNDER DIFFERENT PROCESS CONDITIONS

CARACTERÍSTICAS VISCOELÁSTICAS DEL PAN PRE-HORNEADO BAJO DIFERENTES CONDICIONES DE PROCESO

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RESUMEN

Los estudios reológicos en los alimentos han mostrado que se afectan por los cambios químicos en procesos de elaboración de alimentos. En panificación, la viscoelasticidad de la masa es afectada por los cambios producidos por el horneado y son reflejados en el volumen del pan. El objetivo de esta investigación fue estudiar el efecto de la velocidad de congelación, tiempo de pre-horneado y tiempo de almacenamiento en la viscoelasticidad y volumen específico del pan horneado completamente. Se elaboró masa de harina de trigo para evaluaciones viscoelásticas. La masa fue pre-horneada por 0, 3 o 6 min, luego congelada a dos velocidades: lenta (0.15°C/min) o rápida (1.45°C/min) y almacenada por 56 días. Cada 14 días, muestras de pan pre-horneado fueron descongeladas para realizar evaluaciones reológicas que incluyeron: el módulo elástico (G'), módulo viscoso (G") y tangente delta (Tan δ). Otra parte de las muestras descongeladas fueron horneadas completamente hasta completar 10 minutos y se midió volumen específico del pan. Se utilizó un diseño factorial de 3x2x5 y se llevó a cabo un análisis de varianza con 95% de confiabilidad. El módulo elástico (G') incrementó con el tiempo de pre-horneado. Al incrementar el tiempo de almacenamiento incrementó la G' de la masa y el pan pre-horneado. El tiempo de pre-horneado disminuyó la Tan δ, incrementando la elasticidad en la masa y el pan pre-horneado. Al incrementar el tiempo de pre-horneado disminuyó la temperatura de gelatinización máxima en todos los tiempos de almacenamiento. El volumen específico del pan completamente horneado incrementó con el tiempo de pre-horneado, sin embargo, este parámetro disminuyó con el tiempo de almacenamiento.

Palabras clave*:* Pan pre-horneado, Tiempo de pre-horneado, Viscoelasticidad, Volumen del pan.

ABSTRACT

Rheological studies in food have shown chemical changes during their preparation process. In bread making, dough viscoelasticity studies reflect the chemical changes produced by the baking process, which in turn modifies bread volume. The aim of this research was to study the effect of the freezing rate, part-baking and storage time on the viscoelastic properties and specific volume of part-baked bread and the specific volume of bread completely baked. We prepared water-flour dough for viscoelastic evaluations. Formulated dough for part-baked bread was baked for 0, 3 or 6 min, frozen at two freezing rates: slow (0.15°C/min) or fast (1.45°C/min) and stored for 56 days. Every 14 days, par-baked bread frozen samples were thawed for rheological evaluations including: elastic moduli (G´), viscous moduli (G¨) and Tan δ. Another part of the thawed samples was re-baked (complete baked) to complete 10 min and the specific volume of bread was measured. We used a 3x2x5 factorial design experiment. An analysis of variance was carried out with 95% confidence level. The elastic moduli (G') increased with part-baking time. Part-baking time decreased Tan δ, increasing the elasticity in dough and part-baked bread. Part-baking time decreased gelatinization temperature peak in all frozen storage time. A longer storage time resulted in an increase in the elasticity of dough and part-baked bread. The specific volume of bread increased with part-baking time, however, this parameter decreased with storage time.

Keywords. Part-baked bread, Part-baking time, Viscoelasticity, Bread volume.

INTRODUCTION

Evaluation of the rheological properties is a very useful tool for observing chemical and physical changes in food at the molecular level. Chemical changes are related to changes in rheological behavior (Huang *et al.*, 2008). In baking, extensibility, elasticity, toughness, texture and viscoelasticity are rheological parameters, which directly influence in the specific volume of bread.

The part-baking process is a very common method for bread making. Baking industries save money and benefits in terms of logistics and time. However, there is a reduction of bread volume and quality due to the freezing and storage processes (Rosell *et al.*, 2001). During baking processes, storage temperature, water content, and other process conditions must be considered (Rouille *et al.,* 2000). All of these factors affect the rheological behavior, which involves starch, proteins and water due to that affect the starch gelatinization, reduction and denaturation of proteins and water re-

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distribution, phenomena that change the viscous and elastic parts of the dough and part-baked bread.

In the part-baking bread process, the oven temperature and the freezing and storage conditions affect the components of the dough (starch, protein and arabinoxylans). Part-baking causes low bread quality, and rheological tests make it possible to detect such problems. Additionally, use of the oscillatory dynamic test helps to detect the viscoelastic linear region and to determine the extent of damage to dough structures. This test has been used by different researchers for frozen dough and part-baked bread (Edwards *et al.*, 2001; Lee *et al.*, 2003; Boom, 2006; Zheng *et al*., 2000; Correa *et al*., 2010; Dobraszczyk *et al.*, 2003). The method applies a small stress in an oscillatory way with a low strain to the sample. Some studies have shown that viscoelasticity links directly to gluten polymers. Glutenin is responsible for elasticity and extensibility, and gliadins are responsible for viscosity (Lee *et al*., 2003). The nature of some processes, such as the use of frozen dough or part-baked bread, involves breaking the disulfide bonds formed between subunits of high molecular weight glutenin (HMW-GLU) due to freezing and storage conditions (Barcenas *et al*., 2003; Giannou *et al*., 2005; Ribotta *et al*., 2004; Yi and Kerr, 2009). This causes a low capacity for the gluten network to retain CO_2, resulting in the formation of a dense breadcrumb with less volume.

The addition of ingredients necessary for baking, such as salt, shortenings, yeast and other additives, also affect dough viscoelasticity (Anon *et al.*, 2004). Some studies have shown that each ingredient has an effect (Selomulyo and Zhuo, 2007). For instance, salt competes for the moisture present in the dough and gives cohesiveness, while shortenings hinder water distribution due to their hydrophobic nature, causing the moisture to flow more slowly out of the crumb. Other anti-aging additives usually retain moisture and retard starch retrogradation (Barcenas *et al*., 2004). Considering the viscous (G'') and elastic (G') parts of the dough in viscoelasticity analysis, it is possible to identify the processes and conditions that affect starch and proteins as well as their relation with dough moisture content (Salvador *et al.*, 2006). Starch increases water absorption, as consequence, the viscous part is highest than the elastic part. In addition, rheological studies can provide information regarding gelatinization and viscosity changes with different treatments. The aim of this work was to study the effect of part-baking time, storage time and freezing rate on the viscoelastic and volume properties of part-baked bread. This will allow us to determine the most suitable conditions to increase volume of bread by means of rheological tests.

MATERIALS AND METHODS

Wheat flour was obtained from the milling of Kronstad wheat cultivar grown in the Yaqui Valley, Sonora México. Fresh yeast (Azteca S.A. of C.V., Guadalajara, México) was provided by MUNSA (Obregón, Sonora, México). Shortening (Inca, ACH Foods México, S. de R.L. de C.V) and salt (Mar de Cortés, México) were obtained from a local store in Hermosillo, Sonora México. Flour physicochemical characterization included moisture content (44-40 AACC, 2000), protein content (46-13 AACC, 2000) and ash content (08-03 AACC, 2000). Water absorption was determined with a farinograph (54-21 AACC, 2000),

Bread formulation

To make bread, a French type recipe was used: wheat flour (100%), shortening (5%), fresh yeast (3%) and salt (1.5%).

Dough preparation

Ingredients were weighed on a scale (OHAUS 700/800 series, US) and homogenized for 4 min in a mixer (National MFG brand, Lincoln, NE, US) with the required water obtained from the farinograph (Brabender Instruments, model 810143, South Hackensack, NJ, USA). Dough was divided into 50g portions. Fermentation was carried out in a proofing chamber (National MFG brand, Lincoln, NE, US) at 30°C and a relative humidity (RH) of 85% for 60 min. In addition, dough was also prepared with only flour and water for comparison purposes.

Part-baking, freezing and storage

The fermented dough was part-baked in an oven (National MFG, Lincoln, NE, US) for 0, 3 or 6 min at 250°C. Next, part-baked bread was allowed to rest for 1 h until it had cooled up to 25°C and . Subsequently, it was placed inside an airtight bag. Each sample was frozen at -20°C using a slow freezing process (0.15°C/min) in a freezer (Frigidaire, model GLFC1526FW, Mississauga, Ont., Canada), or using a fast freezing rate (1.45°C/min) in an ultra-freezer (Thermo Fisher Scientific LCC, model UXF40086A62, Asheville, NC USA). Both water-flour dough and part-baked bread were stored for 56 days in a horizontal freezer at -20°C.

Dough and part-baked bread thawing

Every 14 days, frozen samples were thawed until they reached 4°C in a refrigerator (Whirlpool brand, Model ETI8NKXANO3, Whirlpool Corporation, Benton Harbor, MI, USA). The part-baked bread and water-flour dough were allowed to rest in a proofing chamber (National MFG brand, Lincoln, NE, US) at a relative humidity (RH) of 85% and temperature of 30°C, and used for viscoelastic tests.

Viscoelasticity evaluation

Frequency sweep test

For thawed water-flour dough and part-baked bread, frequency sweep tests were performed. Three-gram samples were placed in a rheometer (Rheometrics Scientific, Model RSF III, Piscataway, NJ, USA). Conditions used were: parallel plates of 25 mm diameter, a gap of 2 mm, a strain of 0.1% (linear region of viscoelasticity) and a frequency range of 0.1 to 100 rad/s. Samples were sealed with petroleum jelly to avoid dryness. The viscoelastic parameters determined were moduli of elasticity (G'), moduli of viscosity (G'') and tangent delta (Tan δ).

Temperature sweep test

Thawed samples of 3 g were placed in a rheometer, using the following conditions: parallel plates of 25 mm diameter, gap of 2 mm, strain of 0.1%, frequency of 5 rad/s and a temperature sweep range from 25 to 120°C. The viscoelastic parameters determined were moduli of elasticity (G'), moduli of viscosity (G") and tangent delta (Tan δ).

Specific volume of bread

Thawed part-baked bread samples were complete baked until complete 10 min in the oven. Baked breads were cold for 1h to reach 25°C. Specific volume (SV) was measured according to the rapeseed displacement method using a measurer (National MFG Co. PUP, Lincoln, NE, USA). The weight of bread was obtained with a scale (OHAUS 700/800 series, US). The specific volume was the bread volume and weight ratio (10-09 AACC method 2000).

Experiment design and statistical analysis

Using a 2x3x5 factorial experiment design, factors and levels for part-baked bread considered were: part-baking time (0, 3 or 6 min), storage time (0, 14, 28, 42 or 56 days) and freezing rate (slow 0.15°C/min or fast 1.75°C/min). All data were evaluated using an analysis of variance (ANOVA) with 95% significance. For statistical analyses of the frequency sweep viscoelastic test, data at 5 rad/s from G´, G´´, and Tan δ were used (linear viscoelastic region), while for the temperature sweep test data at 80ºC from G´, G´´, and Tan δ were used (maximum G', G" and Tan δ). The SAS 9.4 statistical software (SAS, 2012) was used for statistical analysis.

RESULTS AND DISCUSSION

Table 1 presents the physicochemical analysis of the wheat flour used. The parameter values reported from flour proximal analyzes are within the values required by the Food and Drug Administration (FDA) regulations. The amount of protein obtained was suitable to prepare French bread type.

Table 1. Physicochemical analysis of flour obtained of Kronstad wheat cultivar.
Tabla 1. Análisis fisicoquímicos de harina de trigo de la variedad Kronstad.

Analysis	Mean
Moisture content (%)	14.15 ± 0.08[a]
Ash content (%)[b]	0.96 ± 0.02
Protein content (%)[b]	12.50 ± 0.14
pH	6.85 ± 0.02
Water absorption (%)[c]	60

[a] Standard deviation
[b] Dry basis
[C] Obtained from the farinograph

Part-baked bread viscoelasticity

Frequency sweep test

The analysis of variance (ANOVA) showed that part-baking time, storage time and freezing rate affected very significantly (P<0.01) the viscoelastic parameters G', G" and Tan δ (Table 2). Figure 1 presents the effect of part-baking times, storage times and freezing rates on G´. In addition, it is also included G' for water-flour dough.

Table 2. Analysis of variance, F value, effect of part-baking time, freezing rate and frozen storage time on G', G" and specific volume of bread.
Tabla 2. Análisis de varianza, valor de F, efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre G', G" y volumen específico del pan.

		F				
VS[a]	DF	FG'[b]	FG"[b]	TG'[C]	TG"[C]	SV[d]
Part-baking time (PBT)	2	6260**[f]	4413**	564.3**	122.5**	1256**
Freezing rate (FR)	1	5.84*[e]	71.82**	5181**	69.56**	2235**
Frozen storage time (FST)	4	28.73**	61.25**	4968**	2851**	20.25**
PBT*FR	2	15.99**	8.46**	2010**	188.7**	40.10**
PBT*FST	5	37.3**	33.02**	1366**	184.2**	4.18**
FR*FST	4	100.7**	143**	8386**	1085**	3.55*
ERROR	60					
TOTAL	78					

[a] VS, variation source; DF, degree of freedom; FG', storage modulus (frequency sweep test); FG", loss modulus (frequency sweep test); TG', storage modulus (temperature sweep test); TG", loss modulus (temperature sweep test)
[b] Value obtained at frequency of 5 rad/s (linear region)
[c] Maximum G´ and G´´ values at 80ºC
[d] SV, specific volume
[d] ns, no significative (P>0.05)
[e] Significative (P<0.05)
[f] Very significative (P<0.01)

In general, G' increased linearly with frequency for all treatments up to 50 rad/s. However, at frequencies higher than 50 rad/s, G´ values became disordered. There was an increase in the variation of the modulus of elasticity, probably occurred due to the break of the structure of polymers such as proteins generated by high frequencies. It is possible that the protein structure loses its original conformational arrangement and reverted to simpler forms, causing great variation in G' (Rosell *et al.*, 2001). In contrast, results obtained on the part-baking time effect show that, at 0 min of baking and any storage time and freezing rate, G' had the lowest values compared to 3 and 6 min of part-baking time. This most likely occurred because bread had not yet baked and, thus, the firmness of the crumb had not developed. Low G' values were also observed in water-flour dough. At 3 min of part-baking time, G' increased for all storage times and both slow and fast freezing rates. The same trend was observed for 6 min of part-baking time. In the oven, starch gelatinization and protein denaturation occur due to the baking temperature, which causes a transfer of moisture from the crumb to

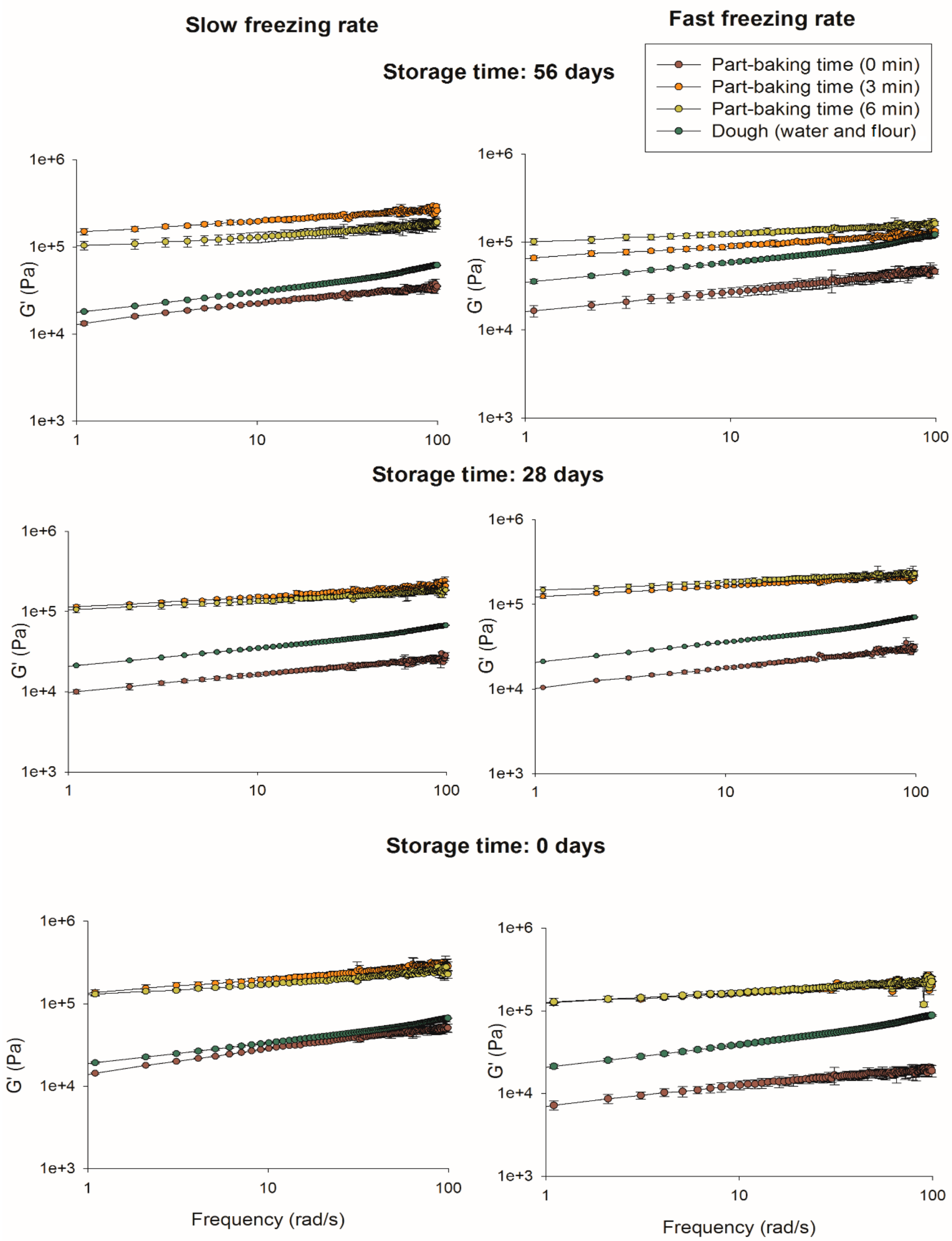

Figure 1. Effect of part-baking time, freezing rate and freezing storage time in G' as a function of frequency on part-baked bread. Bars indicate standard deviation.

Figura 1. Efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre G' como una función de frecuencia en pan pre-horneado. Las barras indican la desviación estándar.

the outside (crust). In dough made only from flour and water the moduli of elasticity is greater than in formulated dough. Ingredients such as salt give more tenacity to the dough and shortening increases the machinability (Anon *et al.*, 2004). According to studies carry out by Huang *et al.* (2008), shortening added to the dough for bread making has a protective effect on starch granules of the flour. This causes a lower starch gelatinization to preserve the whole granule, which results in a decrease of the G´ in dough with shortening.

Another possible cause of low modulus of elasticity in formulated dough is the presence of yeast. When dough is frozen, yeast is subjected to stress at low temperatures, producing glutathione, which is a reducing compound that forms disulfide bonds (S-S) with sulfhydryl (SH) groups (Giannou *et al.*, 2005). This produces breakdown of high molecular weight glutenin chains (HMW-GLU), which causes a decrease in the modulus of elasticity. Hence, the gluten network CO_2 retention capacity also decreases (Yi and Kerr, 2009).

Regarding the freezing rate effect, the results obtained indicated that part-baked bread had larger G' values using fast freezing rate compared with a slow freezing rate. It is possible that this occurs because at a lower freezing rate, the damage caused to the disulfide bonds and a lower water distribution in the system will cause less damage to the gluten.

The ANOVA (Table 2) shows that part-baking time, storage time and freezing rate had very significant ($P<0.01$) effects on the viscous moduli (G''). Figure 2 presents the effect of part-baking time, storage time and freezing rate on G''. In general, the behavior of G'' was similar to that of G' with the same factors. However, G'' values were lower than G´. G'' increased with part-baking time in the dough formulated for bread making. Regarding storage time, at any part-baking time and freezing rate, G'' increased slightly but significantly ($P<0.05$) from 0 to 56 days. Kieffer *et al.* (1998) carried out research with a fast freezing rate and found less damage to the gluten network, which is consistent with our studies. At any storage time, the viscous moduli was lower with a fast freezing rate than slow freezing rate, which could mean less gluten weakening and less rupture of disulfide bonds (Rahaman *et al.*, 2016).

The ANOVA (Table 2) shows than part-baking time, storage time and freezing rate affected very significantly ($P<0.01$) to Tan δ (G''/G'). Figure 3 shows the effect of part-baking time, storage time and freezing rate on Tan δ of dough and part-baked bread. Results of Tan δ were similar to those obtained for G' and G''. At any storage time, Tan δ decreased as the part-baking time increased (more elastic

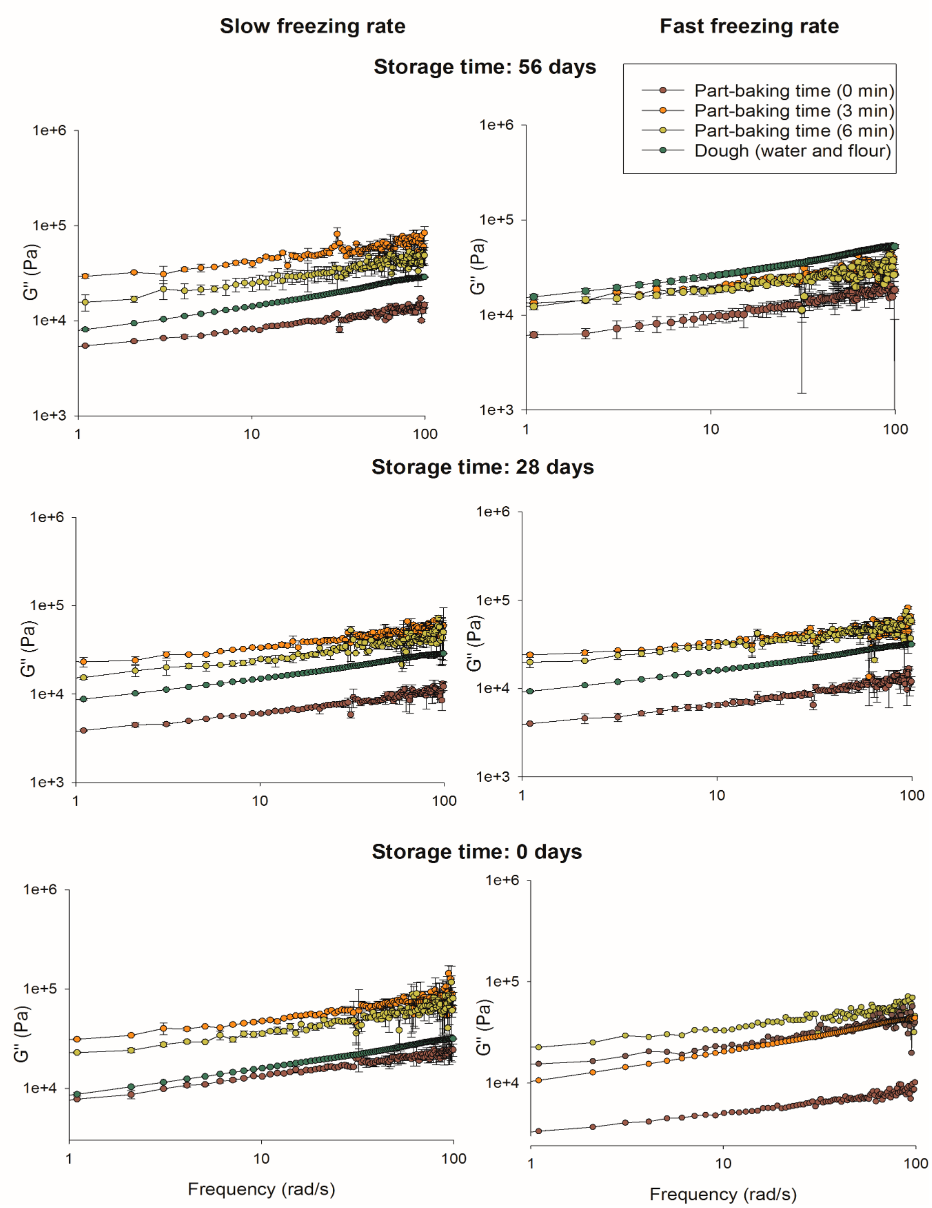

Figure 2. Effect of part-baking time, freezing rate and freezing storage time in G'' as a function of frequency on part-baked bread. Bars indicate standard deviation.
Figura 2. Efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre G'' como una función de frecuencia en pan pre-horneado. Las barras indican la desviación estándar.

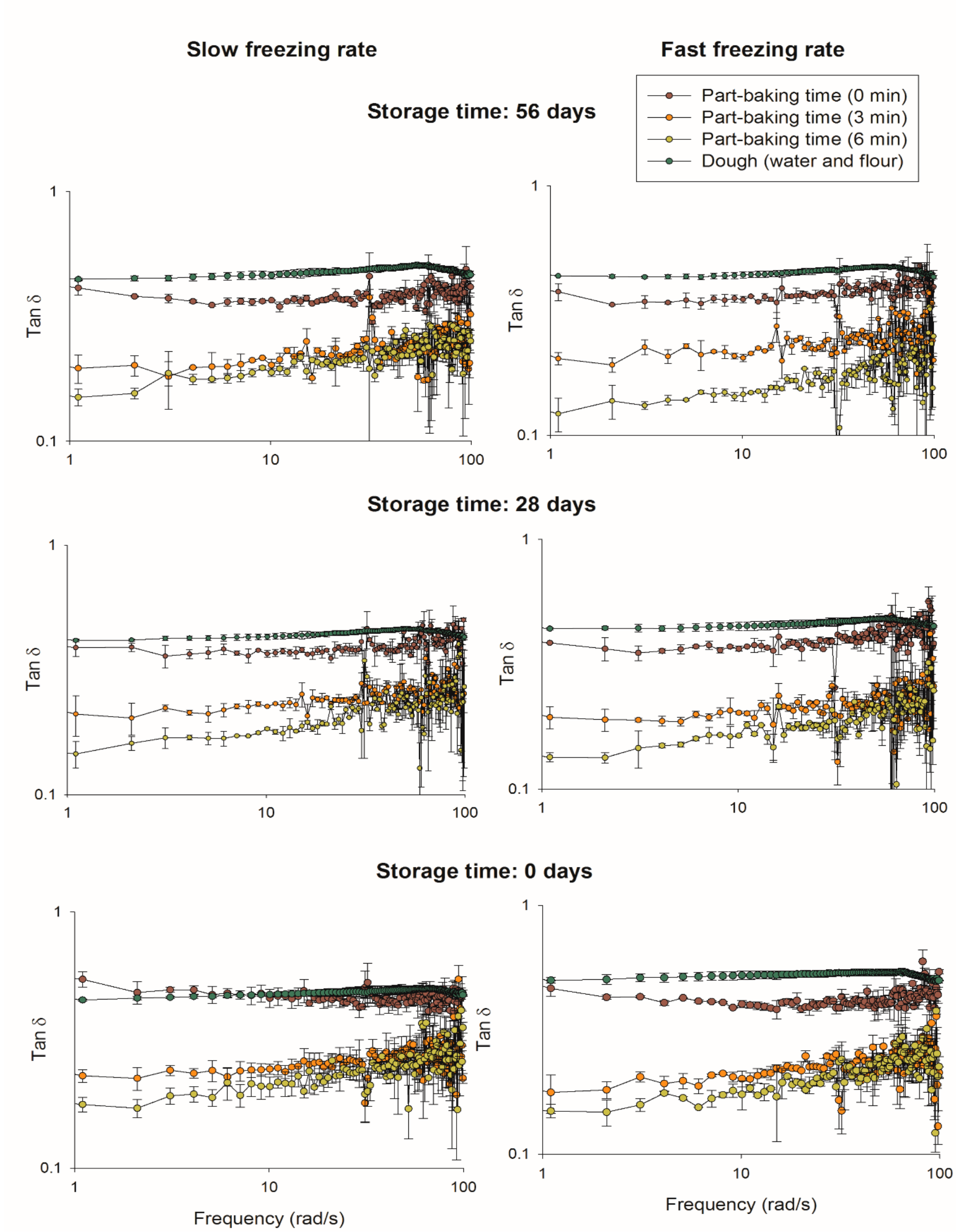

Figure 3. Effect of part-baking time, freezing rate and freezing storage time in Tan δ as a function of frequency on part-baked bread. Bars indicate standard deviation.
Figura 3. Efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre Tan δ como una función de frecuencia en pan pre-horneado. Las barras indican la desviación estándar.

behavior), indicating a solid-like behavior. In addition, at higher frequencies, the instability of Tan δ increased, which could be to break structure of the dough polymers such as proteins.

The flour-water dough demonstrated behavior that was more viscous than elastic compared to the dough formulated for bread making. This behavior might arise because formulated dough incorporates salt and shortening, which give stability to retain moisture and interrupt water redistribution due to freezing and storage, thereby reducing the loss of moisture in the thawing process (Anon, 2004).

Regarding the storage time, for both freezing rate and the three part-baking times, the trend of Tan δ was to decrease slightly but significantly ($P<0.05$) with increased storage time. This means that part-baked bread becomes more elastic than viscous with increasing storage time.

For the freezing rate, part-baked bread had higher elastic to viscous ratio with a fast freezing rate than with a slow freezing rate. This probably indicates less damage to the disulfide bonds because there was not enough time for the formation of large and ordered crystals. Ice formation remains in the nucleation stage, and there is less water redistribution, resulting in the precipitation of the proteins (Leray *et al.*, 2010).

In general, the effect of water redistribution and crystal formation damages glutenins due to breaking down disulfide bonds, which weakens gluten and results in poor-quality bread (Barcenas *et al.*, 2003). The difference in the behavior of the doughs could be the effect of moisture loss in thawing, which influences more than disulfide bond reduction.

Temperature sweep test

The ANOVA (Table 2) indicated that part-baking time, storage time and freezing rate were the most significant factors (P<0.01) affecting G' for part-baked bread. Figure 4 shows the effect of part-baking time, storage time and freezing rate on G' of part-baked bread in the temperature sweep test. The effect of part-baking time at any storage time and freezing rate on G' of part-baked bread was similar with increasing temperature in this test. At 0 min of part-baking time, dough (both water-flour and formulated) had a peak in G' after 60°C. This was probably due to the grain starch gelatinization, which led to water absorption and a disorder of chains of amylose and amylopectin (Ribotta *et al.*, 2003). Subsequently, the breaking of the granule results in a decrease in stress, due to the release of polymers to the outside of the starch granule (Ziobro, 2012). In contrast, at 3 or 6 min of part-baking time, there was not a maximum peak of G', and the curves decreased slightly with temperature, the most of the starch had already gelatinized due to the baking

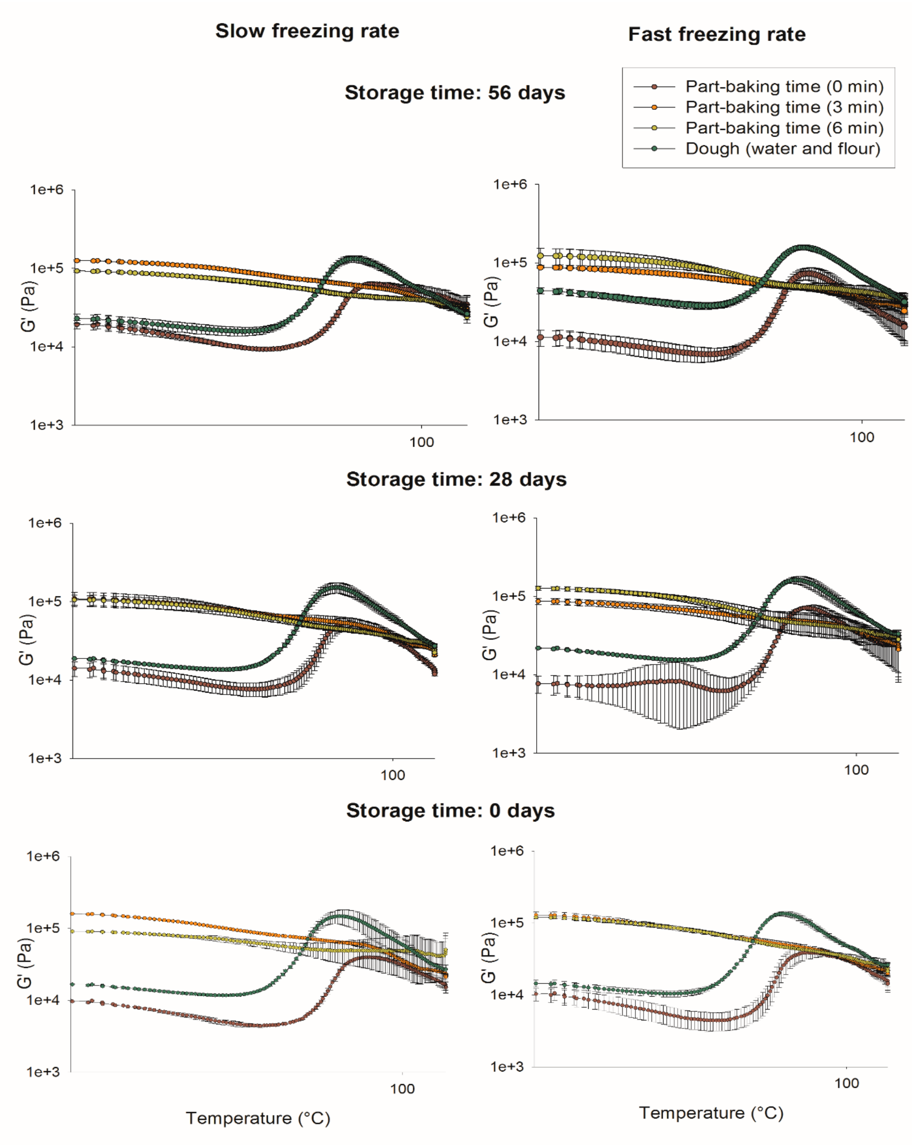

Figure 4. Effect of part-baking time, freezing rate and freezing storage time in G' as a function of temperature in part-baked bread. Bars indicate standard deviation.
Figura 4. Efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre G' como una función de temperatura en pan pre-horneado. Las barras indican la desviación estándar.

temperature. In addition, at high temperatures, there was disruption of the components of the dough. This could be due to denaturation of proteins as well as increased movement of water particles (Peng *et al*., 2017). Regarding storage time, at any part-baking time and freezing rate, G´ increased significantly from 0 to 56 days.

For the freezing rate, at any part-baking time and storage time, fast freezing rate led to a higher elastic modulus than slow freezing rate. This probably indicates less damage to the gluten network. This is the same explanation given for elastic moduli in the frequency sweep test. The increase in the elastic modulus is possibly due to the loss of moisture when the sample is thawed (Bhattacharya *et al*., 2003).

The ANOVA (Table 2) indicated that part-baking time, storage time and freezing rate were the most significant factors (P<0.01) affecting G" of part-baked bread. Figure 5 shows than G" behavior was similar to G' in temperature sweep test, however, G" values were lower. As observed for G', dough (0 min either water-flour or dough formulated for bread making) showed an increase in G" due to the increase in viscosity for the starch gelatinization followed by a decrease in G" due probably to hydrolysis of the polymer chains (Meziani *et al*., 2011). This polymer becomes more unstable at the end of the temperature sweep test. However, for storage time and any part-baking time and freezing rate, G" increased significantly from 0 to 56 days.

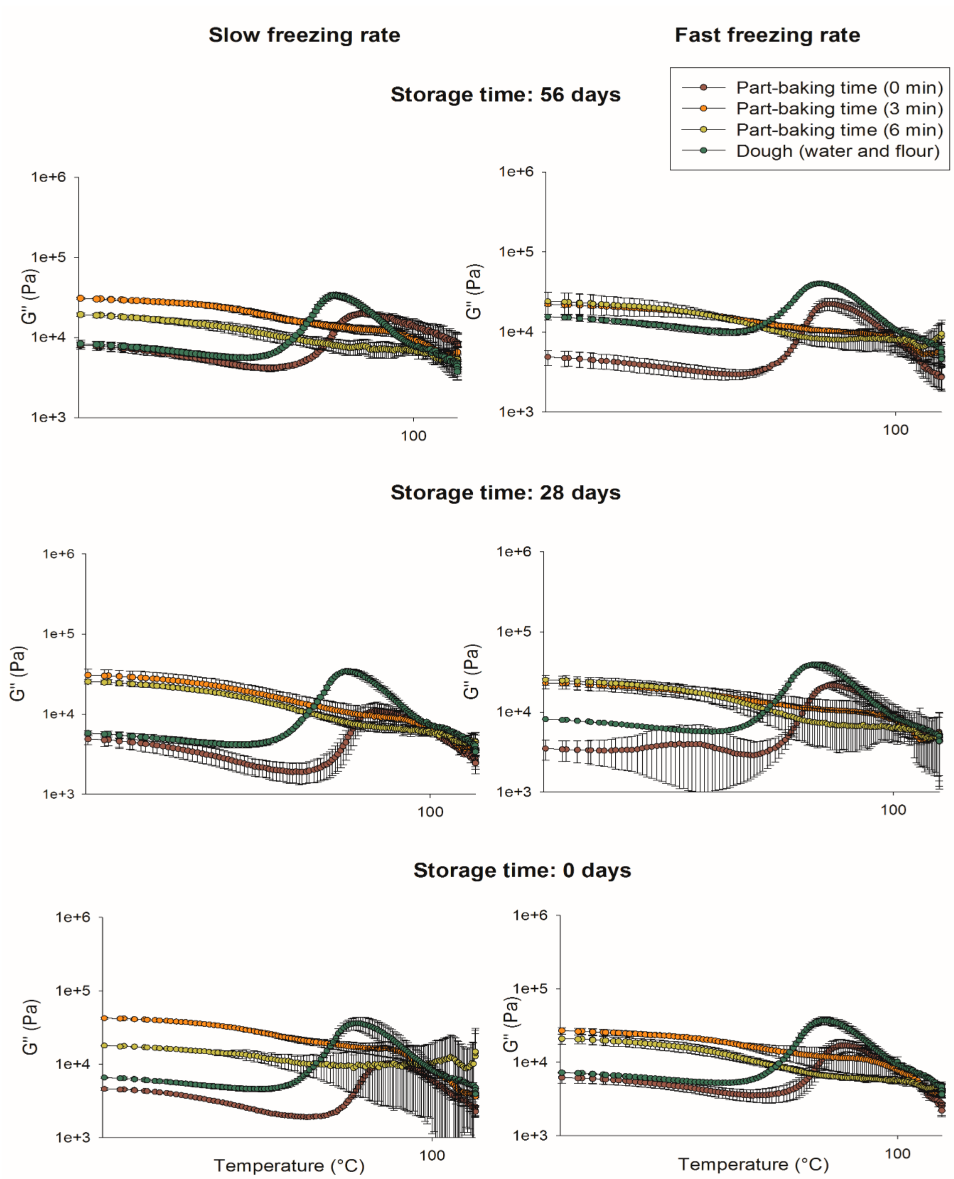

Figure 5. Effect of part-baking time, freezing rate and freezing storage time in G" as a function of temperature in part-baked bread. Bars indicate standard deviation.

Figura 5. Efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre G" como una función de temperatura en pan pre-horneado. Las barras indican la desviación estándar.

Regarding freezing rate, at any part-baking time and storage time, G' with fast freezing rate was significantly higher than slow freezing rate.

The ANOVA (Table 2) indicated that part-baking time, storage time and freezing rate were the most significant factors (P<0.01) affecting Tan δ of part-baked bread. Figure 6 shows the effect of part-baking time, storage time and freezing rate on Tan δ of part-baked bread.

The effect of part-baking time shows that at any storage time and freezing rate, Tan δ decreased from 0 to 6 min. All doughs (either water-flour or formulated for bread making) displayed a peak in the curve at high temperatures. For partial baking times of 3 and 6 min, Tan δ was constant, but it increased slightly and was very variable at high temperatures, this was probably due to the break of structures.

For dough (either water-flour or dough formulated for bread making) Tan δ decreased after the peak of starch gelatinization probably due to the formation of hydrophobic bonds between the polymer chains of the denatured proteins for water redistribution and evaporation (Georget *et al.*, 2006). Dough became a firmer material (behavior like a solid hook). The viscous part decreased at 3 and 6 min of baking time probably due to less moisture present in the part-baked bread than there was at 0 min of baking. A decrease in Tan δ indicated that the elastic proportion of the part-baked bread increased.

Regarding to storage time, Tan δ decreased significantly (P<0.05) from 0 to 56 days for both freezing rates. As

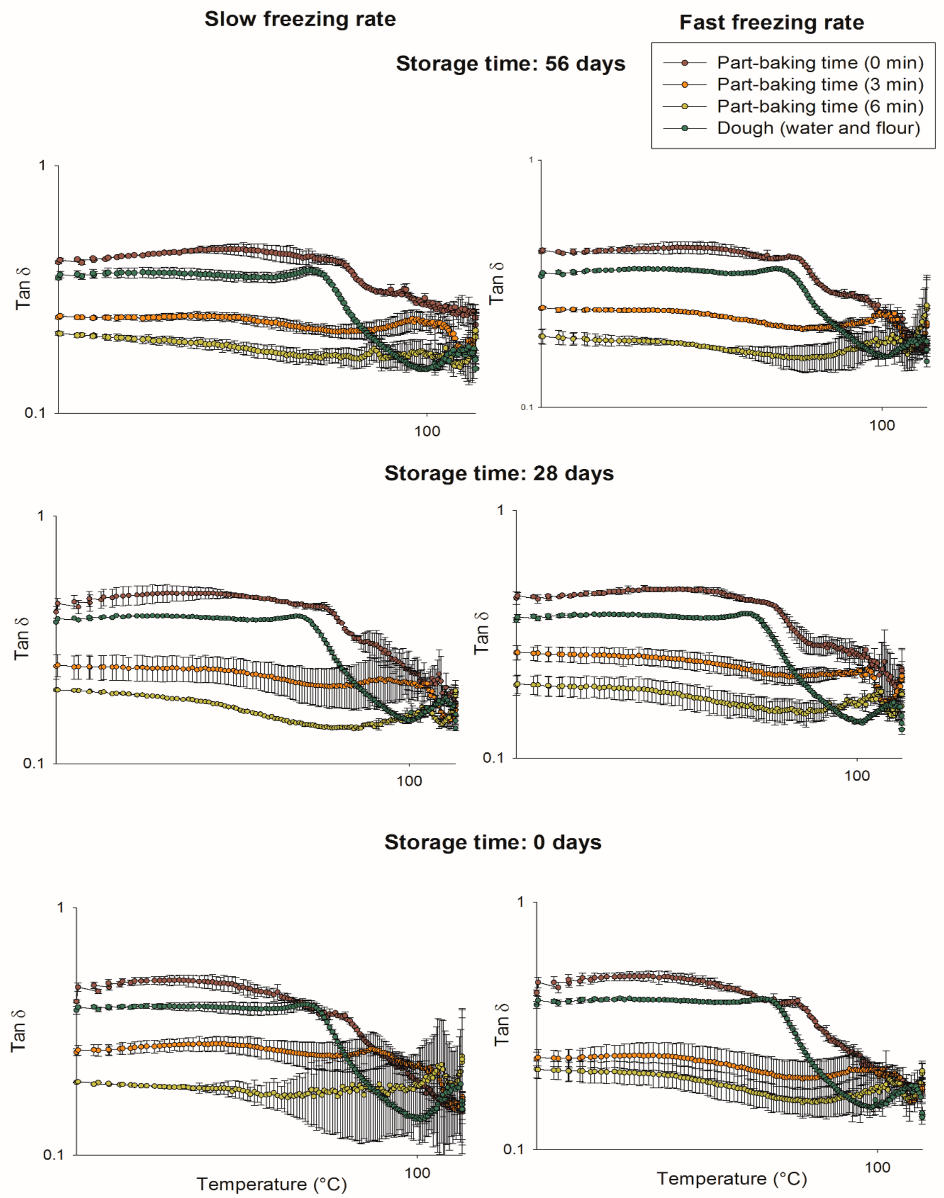

Figure 6. Effect of part-baking time, freezing rate and freezing storage time in Tan δ as a function of temperature in part-baked bread. Bars indicate standard deviation.

Figura 6. Efecto del tiempo de pre-horneado, velocidad de congelación y tiempo de almacenamiento en congelación sobre Tan δ como una función de temperatura en pan pre-horneado. Las barras indican la desviación estándar.

mentioned previously, the loss of water during thawing affects the breakdown of disulfide bonds caused by ice crystals (Angioloni, 2008).

With respect to the freezing rate, Tan δ was significantly (P<0.05) higher with fast freezing than slow freezing rate for all part-baking times and storage times.

Specific volume of bread

The ANOVA (Table 2) shows specific volume of bread was significantly affected (P<0.01) by the part-baking time and storage time. Figure 7 shows the effect of part-baking time and storage time on specific volume of part-baked bread. The specific volume of bread increased with 3 and 6 min of part-baking time. However, specific volume decreased with frozen storage time. When fermented dough is frozen (0 min of part-baking), ice crystals formation with both freezing rates damages the gluten network structure and gluten-starch association is disrupted. The redistribution and recrystallization of water affects proteins, giving rise to discontinuous regions of gluten without the support of the water lamellae (Giannou *et al.*, 2005). This causes a loss of gas retained in the alveolus, therefore, when thawing the dough it is unable to retain CO_2, resulting in loaf with low volume (Rosell *et al*., 2001). After 3 min of part-baked, temperature still does not reach the bread center, so it is possible that the "oven-spring" phenomenon is not complete. The freezing process stops the yeasts action and a smaller volume is obtained with 3 min than with 6 min of part-baked. Six min of part-baking time where gives an optimum of fermentation and the structure of the bread is formed before freezing.

The above resulted at any frozen storage time. Volume of part-baked bread decreases due probably to temperature fluctuations causing the formation of larger crystals. In the presence of yeasts, they release glutathione, which reduces disulfide bonds and weakens the gluten network (Barcenas *et al.*, 2004).

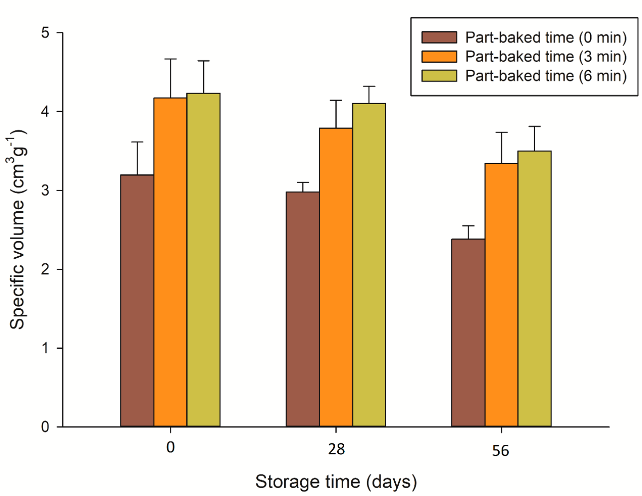

Figure 7. Effect of part-baking time and freezing storage time in the specific volume of bread. Bars indicate standard deviation.
Figura 7. Efecto del tiempo de pre-horneado y tiempo de almacenamiento en congelación sobre el volumen específico del pan. Las barras indican la desviación estándar.

Figure 8 shows the results of the effect of freezing rate and storage time on the specific volume of bread. The slow freezing rate had a higher specific volume for 0 and 28 days of storage, however, bread frozen with fast freezing rate had low decrease of volume than slow freezing rate. The formation of larger crystals, coupled with the recrystallization of water affected the gluten network (Selomulyo and Zhuo, 2007). However, with fast freezing rate, there was probably redistribution of water and the freezing process stopped at the nucleation stage even with the storage time.

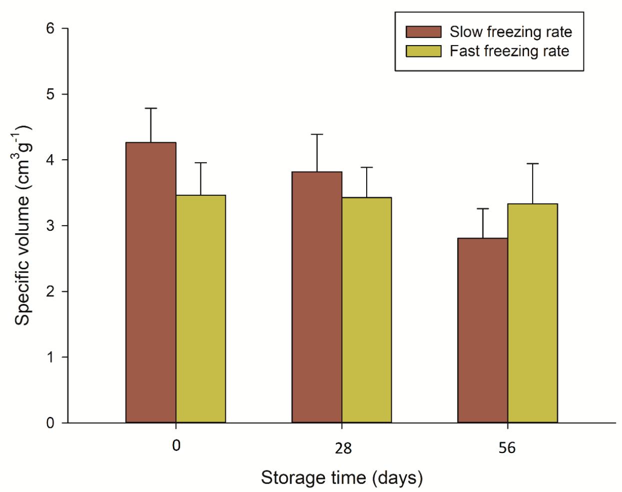

Figure 8. Effect freezing rate and freezing storage time in the specific volume of bread. Bars indicate standard deviation.
Figura 8. Efecto de la velocidad de congelación y tiempo de almacenamiento en congelación sobre el volumen específico del pan. Las barras indican la desviación estándar.

CONCLUSIONS

Part-baking time was the factor that most affected the viscoelastic properties of part-baked bread as well as the bread specific volume, followed by freezing rate and frozen storage time. The part-baking time increases G' and G" and decreases gelatinization peaks for all storage times. In most cases, storage time generates an increase in the elasticity of the dough and part-baked bread. Part-baking time decreased Tan δ increasing the elasticity in dough and part-baked bread. Part-baking time at 3 and 6 min decreased gelatinization temperature peak in all storage time. The fast freezing rate is more beneficial, causing less damage to the gluten network. At 6 min of part-baked, specific volume was highest than 0 and 3 min, and specific volume of bread decrease with frozen storage time. The information generated in this study may be useful for considering the conditions of a process used to produce higher quality part-baked bread.

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