Rheological properties and bread quality of frozen sweet dough with added xanthan and different freezing rate

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Abstract In this paper the effects of frozen storage time, xanthan gum and rate of freezing on frozen sweet dough properties and unfermented bread quality was investigated. Results revealed that the water holding capacity, WHC, K_1 (stress decay rate) and K_2 (residual stress at the end of the stress relaxation experiment) values of frozen dough decreased with increasing frozen storage time and decreasing freezing rate; while the lowest values for these parameters were obtained for samples without xanthan gum. The amount of unfreezable water increased and freezable water decreased with addition of xanthan gum. Glass transition temperature for fresh or frozen sweet were around -37 and -39 °C, respectively. Addition of xanthan gum increased the glass transition temperature of fresh and frozen sweet dough. Firmness and gumminess of sweet bread increased during frozen storage which led to lower specific volume of frozen sweet bread. Increasing freezing rate and addition of xanthan gum to dough formulation improved the texture and specific volume of the final bread.

Keywords Frozen sweet dough · Stress relaxation · DSC · Frozen storage · TPA · WHC

Introduction

Frozen dough decreased night work and logistic constraints in bakeries. Freezing give longer shelf life and preserve freshness; which greatly depends on the freezing or thawing process (Angioloni et al. 2008). Frozen doughs are becoming common in the bakery industry (Meziani et al. 2011). The unfermented frozen dough allows baking on sale point and does not require staff eligibility, provides fresh products, with high organoleptic and textural properties (Meziani et al. 2011).

The frozen dough lose it's quality during storage (Hua-Neng et al. 2009). Frozen products are susceptible to change during storage; they gently deteriorate and ultimately achieve an unacceptable quality. Several problems such as the increase in liquid, reduction in dough volume, WHC and specific volume compared to dough prepared by traditional methods arised from production of sample from frozen dough (Rosell and Gómez 2007). Concerning product quality, such problems can reduce retailer and consumer acceptance of frozen dough. It is therefore important to acheive a better comprehending of what initiates this deterioration to prevent the quality loss during manufacture (Hua-Neng et al. 2009). Water may be lost when frozen dough is subjected to external forces due to the intrinsic instability of such dough. On the other hand, ice crystallization and recrystallization contributed to the weakening of gluten network and lead to the decrease in product quality during frozen storage and freeze–thaw cycles (Hua-Neng et al. 2009).

The final quality of frozen product is affected by the rate of freezing. A high freezing rate facilitate the formation of ice micro-crystals, which has no effect on the integrity of the three-dimensional gluten network. As a result, physical damage induced by ordinary freezing reduces (Angioloni et al. 2008).

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Using additives is becoming popular in the baking process. Use of water binding compounds, such as hydrocolloids, favours the absorption of moisture that is released following the breakdown of the gluten network (Asghar et al. 2009). Hydrocolloids favour the manufacture of soft samples, through enhancing water retention in the dough (Kim et al. 2008; Kaur et al. 2015). Xanthan gum induces cooking and cooling resistance of wheat flour and increases the freeze–thaw stability of frozen foods (Rosell et al. 2001; Mandala 2005).

Meziani et al. (2011) reported that producing sweet bakery products from frozen dough adds more challenges than those of an unsweetened frozen dough. To better understand the action of frozen storage on sweet dough rheological properties, various investigation methods should be used. Therefore, the objective of this research were (1) to study the visco elastic properties of frozen sweet dough as affected by frozen storage and rate of freezing and (2) to improve the quality of dough and baked sample by addition of xanthan gum.

Materials and methods

Dough preparation

Sweet dough was prepared using the formulation and ingredients from Razavi Company (Mashhad, Iran). The dough recipe comprised: 640 g wheat flour (Kalaleh Industries Co, Iran; moisture 14.2%, ash 0.48%, protein content 10%, wet gluten 25%), 90 g water, 70 g shortening (Elais S.A., Athens, Greece), 184 g sugar (Shirin Co, Mashhad, Iran), 70 g oil (Nastaran Co, Iran), 140 g invert syrup, 30 g egg, 6 g dried milk, 2 g emulsifier (Azarnush Co, Iran), 2.4 g baking powder and 0.5 g vanilla (Silisia, Germany). Xanthan gum from Sigma (St. Louis, MO, USA) was added at 0 and 0.1% flour basis. The added gum concentrations in the final recipe were chosen according to our previous work (unpublished data). All ingredients were put in a mixer (Berjaya, Malaysia) and were mixed at a first speed (475 rpm) for 8 min initially and at a second speed (950 rpm) for 2 min thereafter. Dough temperature was 23 °C at the end of mixing. After mixing, dough was hand-moulded and divided into pieces for measuring the WHC, stress relaxation test and DSC (Mandala 2005). The samples were packed in polyethylene bags for freezing.

Freezing and thawing

Two types of freezing processes were used to treat the dough: Shock freezing (−35 °C, for 30 min, as fast freezing) and usual freezer (−20 °C, for 5 h, as slow

freezing). After freezing, the dough pieces were stored frozen at −18 °C for 0, 2, 4, 6 and 8 weeks. During 8 weeks of storage, some dough pieces were subjected to thawing. For the thawing, the dough pieces were placed in a refrigerator at +4 °C for 120 min, which was adequate for dough to thaw completely (Meziani et al. 2011). After thawing, the pieces of 10 g were subjected to centrifugation for determination of WHC and other pieces of dough were used for stress relaxation test and baking.

WHC of thawed sweet dough

The thawed dough pieces (for 0, 2, 4, 6 and 8 weeks of frozen storage/with slow or fast freezing/with or without xanthan gum) were removed from their bags. The sample (10 g) was accurately weighed and added into the pre-weighed 20 mL centrifuge tube, and then centrifuged at 5000 rpm (2880×g) for 60 min. The clear centrifuged liquid was decanted in a drop wise manner, and the residue was weighed. The weight ratio after and before centrifugation (W/W₀) was used to characterize the WHC of dough (Hua-Neng et al. 2009).

Dough stress relaxation test

Viscoelastic properties related to texture were analyzed using a TA-XT Plus™, Texture Analyzer (Stable Micro Systems, England). The thawed sweet dough were cut into 20 × 20 × 25 mm and compressed. A 50 mm aluminum probe was used in relaxation test to compress each sample to 20% of its original height with a cross head speed of 10 mm/min. The obtained stress relaxation curves were normalized and linearized using Peleg and Normand (1983) Equation (Eq. 1) (Wu et al. 2012; Mandala et al. 2007):

$$\frac{F_0 \times t}{F_0 - F(t)} = K_1 + K_2(t) \quad (1)$$

where F_0 is the initial force, $F(t)$ is the momentary force at time (t) and K_1 , K_2 are constants related to stress decay rate and to residual stress at the end of the experiment (Ghaitaranpour et al. 2013). Relative force (RF) is evaluated for experimental data according to Eq. 2:

$$RF = F(t)/F_0 \quad (2)$$

Baking of thawed sweet dough

The thawed sweet doughs (after 0, 2, 4, 6 and 8 weeks of frozen storage) was hand-moulded, divided into pieces in size of 5 × 6 × 1 cm for baking. The samples were baked in an air oven (FABRIQUE, 28-Eure-et-Loir, convection,

France) for 20 min at 175 °C. After baking, sample was cooled to room temperature and packed into plastic bags. Sample was left at ambient temperature and analyzed within 24 h. All experiments were done with three replications.

Sweet bread texture

Baked sample slices from thawed sweet doughs (for 0, 2, 4, 6 and 8 weeks of frozen storage/with slow or fast freezing/with or without xanthan gum) were characterized for the texture profile analysis carried out with a TA-XT PlusTM, Texture Analyzer (Stable Micro Systems, England), using a 500 N load cell and 50 mm cylindrical probe. The sample slices were compressed at a speed of 1.7 mm s⁻¹ to a total distance of 10 mm (40% strain) and withdrawn at the same speed. The following textural parameters were recorded from the force distance curves: hardness, cohesiveness, springiness, chewiness, and adhesiveness (Ke et al. 2013; Kaur et al. 2016).

Specific volume of baked sweet dough

Volume of the baked sample from thawed sweet doughs (for 0, 14, 28, 42 and 56 days of frozen storage/with slow or fast freezing/with or without xanthan gum) was measured using a rapeseed displacement measuring apparatus. Loaf weight was determined and specific volume was calculated as Eq. (3) (Sharadanant and Khan 2003; Yingying et al. 2014).

$$\text{Specific volume} = \text{loaf volume (cc)}/\text{loaf weight (g)} \quad (3)$$

Differential scanning calorimetry (DSC)

Thermal phase transitions were monitored using a Differential Scanning Calorimeter (DSC 822, METTLER TOLEDO- Switzerland, TSO800GC1, Gas control). Dough samples of 15–20 mg were pressed to the bottom of a Aluminium DSC pan and hermetically sealed. An empty pan was used as the reference and indium (and zink) was used for calibration. The sample was cooled to -70 °C, held isothermally for 3 min, and subsequently heated to 150 °C at 5 °C/min (Simmons et al. 2012). Furthermore, the glass transition temperature (T_g) was measured by DSC according to (Simmons et al. 2012).

The amount of freezable water (FW) was measured using the area under the endothermic peak (AUP) near 0 °C (Nilufer et al. 2008; Simmons et al. 2012):

$$\%FW = \frac{\text{Enthalpy as determined by AUP near } 0^\circ\text{C} \left(\frac{\text{J}}{\text{g sample}} \right)}{\text{Latent heat of fusion of water} = 333.5 \frac{\text{J}}{\text{g water}}} \quad (4)$$

Unfreezable water (UFW) was calculated by subtracting the amount of freezable water from the total water (Vitadini and Vodovotz 2003; Simmons et al. 2012).

Statistical analysis

Analysis of variance were computed using SPSS16 software and the experimental groups. The Duncan multiple-comparison test ($p < 0.05$) was used to compare means. After obtaining the data of time- stress (Eq. 1), Peleg-Normand's model is used to fit the experimental data and the model coefficients (K_1 and K_2) were extracted. The model fitting on experimental data was performed by Excel. Linear regression analysis was used to determination of Peleg-Normand's equations coefficients.

Results and discussion

WHC of thawed sweet dough

Water-holding capacity (WHC) is the ability of sample to hold water. The WHC of frozen dough decreased with increasing frozen storage time (Fig. 1a). This could be due to the ice crystallization in frozen dough during the prolonged storage and thawing (Hua-Neng et al. 2009). Throughout storage, large ice crystals grow at the expense of smaller ones and ruptured the gluten network (Hua-Neng et al. 2009). According to Vania and Weibiao (2007) during extended frozen storage, ice crystallization contributed to the weakening of the gluten network and lowered the bread quality. This was further supported by the findings of Lu and Grant (1999) which showed that the amount of freezable water (the fraction of free water that does not bind to gluten during dough formation) in frozen dough increased during storage in frozen conditions (Vania and Weibiao 2007). The results of the present study were also in good agreement with those reported by Hua-Neng et al. (2009), where the WHC of frozen dough decreased with increasing frozen storage time. Flexible cell components may be stressed in the regions where ice is present and mechanically damages the structures. Growing ice crystals during freezing may also exert stresses on these fragile structures (Mallett 1993).

Moreover, dough frozen with shock freezing technique (fast freezing) had higher WHC than those prepared by slow freezing method. This difference may be attributed to formulations of large size crystals and the mechanical action of these ice crystals during slow freezing. However, fast freezing led to the formation of smaller ice crystals without any consequences on the dough. The

Fig. 1 Effect of frozen storage time, rate of freezing and xanthan gum on **a** WHC of frozen dough, **b** specific volume of baked sample and **c** relationship between WHC of frozen dough and the Specific volume of baked sample from thawed sweet dough

larger the ice crystal size, the weaker the gluten network (Meziani et al. 2011; Angioloni et al. 2008). Therefore, more bounded water will be released after thawing and as a result, WHC of frozen dough decreased (Hua-Neng et al. 2009).

The frozen dough containing xanthan gum had higher WHC ($p < 0.05$). Since xanthan has good water-binding ability (Hasanpour et al. 2012), this may be related to the increase in dough water absorption (Vania and Weibiao 2007; Hasanpour et al. 2012). As a result, adding xanthan gum to the formulation of frozen dough improved dough water retention during frozen storage. Xanthan gum could also improve the dough stability through the formation of strong linkage with flour proteins (Vania and Weibiao 2007; Rosell et al. 2001). Ribotta et al. (2005) found that anionic hydrocolloids may form hydrophilic complexes with gluten proteins. Therefore, lower water will be released after thawing and hence the WHC of dough increases. This property of xanthan gum induces cooking and cooling stability of wheat flour bread and improves the freeze–thaw stability of the frozen dough (Vania and Weibiao 2007). As also mentioned by other researchers, addition of hydrocolloids into frozen products can provide stability during freeze–thaw cycles and help to minimize the negative effects of freezing and frozen storage on starch-based products (Vania and Weibiao 2007).

Dough stress relaxation test

Among cereal flours, only wheat flour can form three-dimensional viscoelastic dough when mixed with water (Yang et al. 2011; Kaushik et al. 2014). As for most viscoelastic materials, after application of a constant strain, a decrease in force values necessary for maintaining the deformation was observed. Relative residual force values for doughs during stress relaxation test decreased with increasing frozen storage time (Table 1). This indicated that the dough had more solid-like behavior at first day of storage, while during frozen storage, dough had lower solid-like behavior. These results could be explained by the gluten network disruption of frozen sweet dough caused by ice crystallization and the water redistribution induced by alteration in water binding capacity of dough components (Havet et al. 2000). During freezing process, the osmotic pressure of the external medium rises and the water efflux from the dough matrix increased (Meziani et al. 2011; Havet et al. 2000). Gélinas and McKinnon (2004) also reported that the sensitivity of gluten network to temperature and freezing condition influence the dough textural properties. The ice formation compresses the network, thereby altering the dough components distribution (Meziani et al. 2011).

The relative residual force values for dough increased with increase in the rate of freezing and addition of xanthan

Table 1 Effect of frozen storage time, freezing rate and xanthan gum on the stress relaxation parameters of sweet dough

Samples	Frozen storage time (days)	K_1	K_2	R^2	Start load (N) (F_0)
Slow freezing/without xanthan	0	13.68 ± 0.16^{ab}	1.10 ± 0.00^a	0.998	6.84 ± 1.08^{fg}
	14	10.48 ± 5.06^b	1.08 ± 0.01^a	0.999	8.64 ± 2.23^{ef}
	28	3.84 ± 0.53^c	1.07 ± 0.04^a	0.999	11.13 ± 1.53^{de}
	42	2.57 ± 0.17^c	1.08 ± 0.00^a	0.999	17.72 ± 0.69^c
	56	2.23 ± 0.29^c	1.04 ± 0.02^{ab}	0.999	29.36 ± 1.6^a
Fast freezing/without xanthan	0	11.77 ± 1.55^{ab}	1.11 ± 0.01^a	0.999	2.84 ± 0.2^h
	14	11.64 ± 2.71^{ab}	1.08 ± 0.00^a	0.999	6.76 ± 1.11^{fg}
	28	3.32 ± 0.18^c	1.07 ± 0.008^a	0.994	11.94 ± 0.34^d
	42	2.3 ± 0.007^c	1.07 ± 0.02^a	0.999	15.67 ± 2.88^c
	56	2.70 ± 0.21^c	1.04 ± 0.001^{ab}	0.999	17.36 ± 0.50^c
Slow freezing/with xanthan	0	15.17 ± 0.96^a	1.08 ± 0.01^a	0.999	8.48 ± 0.75^{ef}
	14	12.18 ± 1.36^{ab}	1.07 ± 0.004^a	0.999	11.18 ± 1.06^{de}
	28	5.31 ± 0.47^c	1.06 ± 0.021^a	0.991	12.63 ± 1.91^d
	42	2.77 ± 0.35^c	1.06 ± 0.005^a	0.999	17.50 ± 1.34^c
	56	2.52 ± 0.011^c	0.97 ± 0.12^b	0.999	26.26 ± 0.03^b
Fast freezing/with xanthan	0	15.53 ± 4.9^a	1.09 ± 0.008^a	0.999	5.09 ± 1.55^{gh}
	14	14.14 ± 2.60^{ab}	1.09 ± 0.04^a	0.999	9.78 ± 0.62^{def}
	28	13.70 ± 0.17^{ab}	1.07 ± 0.00^a	0.999	11.11 ± 1.79^{de}
	42	5.54 ± 1.42^c	1.05 ± 0.02^a	0.999	17.19 ± 0.83^c
	56	2.33 ± 0.12^c	1.04 ± 0.02^{ab}	0.999	25.83 ± 0.52^b

Reported values correspond to the mean $\pm$ standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$) K_1 and K_2 (Peleg–Normand's equations Coefficients) are constants related to stress decay rate and to residual stress at the end of the experiment

gum (Table 1). This indicated that the dough had more solid-like behavior at higher freezing rate and in the presence of xanthan gum. Rheological changes of dough occurred during the slow freezing process may be explained by the formation of large size crystals which damage dough gluten network (Meziani et al. 2011; Angioloni et al. 2008).

The normalized force values determined during stress relaxation tests were well fitted ($R^2 > 0.998$) by Peleg–Normand model. High values of both K_1 and K_2 indicate a more elastic, “solid-like” product. The effects of frozen storage time, freezing rate and xanthan gum on stress relaxation parameters (K_1 and K_2) of thawed sweet dough are shown in Table 1. Lower K_1 values are related to a steeper descent of the relaxation curve toward the residual value during storage (Mandala et al. 2007). Lower K_1 and K_2 values were observed during the frozen storage time. At first day of frozen storage, all samples had the most elastic crumb, while after frozen storage, the elasticity of dough decreased (Table 1). However, there was no significant difference between K_2 of samples in most cases. Mandala (2005) reported that for samples with lower values of K_1 and K_2 , the stress applied relaxes faster and samples are less elastic, having consequently a more pronounced viscous (rubbery) character.

The lowest values for K_1 and K_2 were obtained for samples without xanthan gum while dough containing xanthan gum had the highest stress decay rate constant. Therefore, in the presence of the xanthan gum dough became more elastic after freeze-thawing. Results obtained by Mandala (2005) showed that the addition of xanthan gum generally increased K_1 and K_2 values compared to those of the control samples. Xanthan gum induced dough strengthening along with increase in water absorption (Mandala et al. 2007). These changes may have improved the ability of dough to retain gas and therefore increase the elasticity and solid behaviour of the sweet dough (Mandala 2005).

Although in most cases, K_1 and K_2 of frozen dough increased using increasing the rate of freezing, this effect was not significant (Table 1). This means that the elasticity and solid behavior of samples was independent of the rate of freezing.

The initial force required to induce constant strain at time zero (F_0) for sweet dough increased during frozen storage time and addition of xanthan gum (Table 1). Samples containing xanthan had higher F_0 values and were more rigid than other doughs. In other words, although xanthan gum improved the elasticity (increase in K_2) of dough it increased the sample rigidity. According to Biliaderis et al. (1997) the effect of hydrocolloids on starch

mechanical properties results from two opposite phenomenon. First, an increase in the rigidity as a consequence of decrease in swelling power of starch granules and amylose; and second, by its weakening effect on starch structure due to the inhibition of amylose chain association. However, the weight of each effect depends on the specific hydrocolloids used for formulation.

Almost for all samples, F_0 increased with decreasing the rate of freezing (Table 1). Meziani et al. (2011) also concluded that during slow freezing process, an increase in dough rigidity was observed. According to Angioloni et al. (2008), the rheological changes of dough during slow freezing could be explained by the formation of large ice crystals and the mechanical action of these crystals.

Sweet bread texture

Hardness, cohesiveness, gumminess, springiness and adhesiveness of sweet bread were significantly affected by storage time (Table 2). During dough frozen storage, hardness and gumminess values of bread increased while cohesiveness, springiness and adhesiveness decreased compared to the fresh sample (Table 2). The reduction in elasticity of frozen dough may be due to the disruption of gluten network bonds caused by mechanical action of ice crystals (Havet et al. 2000) that may have resulted in

increase in sweet bread hardness. Angioloni et al. (2008) and Meziani et al. (2012) also reported that the frozen storage period had a negative effect on dough's hardness, springiness and adhesiveness. According to Esteller et al. (2004) the decrease in bread cohesiveness was due to the loss of intermolecular attraction among ingredients. Changes in disulphide, hydrogen, and ionic bonds occur during frozen storage, leads to a gradual disarrangement of dough structure (Esteller et al. 2004). Therefore, a decrease in the intermolecular attraction among ingredients of frozen dough during storage might be the reason for dough aggregation and hence loss in bread cohesiveness.

The freezing method also affected final bread quality. With increase in the freezing rate, bread cohesiveness and springiness increased. In most cases (especially for samples with xanthan gum), increased in freezing rate reduced the sweet bread hardness which gave better texture to the final product. The gluten network disruption decreased as the rate of freezing increased, formation of small ice crystals during fast freezing maintained the ability of dough to retain gas during baking. Therefore, samples containing more gas had softer crumb and better texture.

Meziani et al. (2012) also reported that the hardness of baked product obtained from frozen sweet dough increased significantly as the freezing rates increased. However, Kondakci et al. (2015) concluded that the bread hardness

Table 2 Effect of frozen storage time, freezing rate and xanthan gum on TPA of baked frozen sweet dough

Sample	Frozen storage time (days)	Hardness (N)	Cohesiveness	Gumminess (N)	Adhesiveness (N.S)	Springiness (mm)
Slow freezing/without xanthan	0	27.76 ± 4.29 ^j	0.21 ± 0.01 ^{ab}	5.68 ± 4.43 ^c	0.16 ± 0.14 ^b	2.82 ± 0.25 ^{abcd}
	14	55.33 ± 5.11 ^{hi}	0.15 ± 0.01 ^{bcd}	5.84 ± 0.52 ^c	0.024 ± 0.016 ^b	2.38 ± 0.09 ^{bcd}
	28	89.66 ± 5.78 ^{def}	0.07 ± 0.004 ^{efgh}	7.93 ± 2.14 ^{abc}	0.0038 ± 0.0028 ^b	2.12 ± 0.06 ^{bcd}
	42	137.62 ± 17.16 ^c	0.05 ± 0.01 ^{gh}	8.00 ± 1.02 ^{abc}	0.00071 ± 0.00042 ^b	2.09 ± 1.27 ^{bcd}
	56	160.50 ± 15.68 ^a	0.036 ± 0.03 ^h	13.43 ± 9.71 ^{ab}	0.0004 ± 0.00028 ^b	1.81 ± 0.46 ^{cd}
Fast freezing/without xanthan	0	25.18 ± 3.26 ^j	0.20 ± 0.01 ^{abc}	5.66 ± 1.57 ^c	0.0588 ± 0.028 ^b	3.26 ± 0.05 ^{abc}
	14	78.26 ± 0.58 ^{fg}	0.13 ± 0.04 ^{bcd}	5.75 ± 0.8 ^c	0.049 ± 0.015 ^b	2.55 ± 0.14 ^{bcd}
	28	90.31 ± 6.82 ^{def}	0.09 ± 0.01 ^{defgh}	7.85 ± 1.02 ^{abc}	0.023 ± 0.016 ^b	2.44 ± 0.11 ^{bcd}
	42	93.72 ± 0.03 ^{def}	0.07 ± 0.01 ^{efgh}	11.60 ± 2.02 ^{abc}	0.023 ± 0.014 ^b	2.21 ± 0.05 ^{bcd}
	56	104.75 ± 0.81 ^{de}	0.07 ± 0.02 ^{efgh}	14.12 ± 1.26 ^a	0.0017 ± 0.0014 ^b	1.58 ± 1.37 ^d
Slow freezing/with xanthan	0	22.36 ± 2.13 ^j	0.19 ± 0.02 ^{abc}	4.87 ± 0.003 ^c	0.0588 ± 0.029 ^b	3.26 ± 0.06 ^{abc}
	14	83.10 ± 0.37 ^{efg}	0.17 ± 0.12 ^{abcd}	6.71 ± 0.79 ^{bc}	0.044 ± 0.031 ^b	2.54 ± 0.21 ^{bcd}
	28	85.38 ± 1.79 ^{def}	0.098 ± 0.02 ^{defgh}	7.24 ± 1.07 ^{abc}	0.038 ± 0.021 ^b	2.46 ± 0.02 ^{bcd}
	42	93.20 ± 7.63 ^{def}	0.08 ± 0.01 ^{efgh}	8.90 ± 3.57 ^{abc}	0.011 ± 0.009 ^b	2.44 ± 0.05 ^{bcd}
	56	153.06 ± 4.66 ^{bc}	0.06 ± 0.009 ^{gh}	9.68 ± 0.30 ^{abc}	0.0035 ± 0.0014 ^b	2.18 ± 0.74 ^{bcd}
Fast freezing/with xanthan	0	22.36 ± 16.91 ^j	0.24 ± 0.02 ^a	4.61 ± 0.00 ^c	0.588 ± 0.381 ^a	4.18 ± 1.49 ^a
	14	36.86 ± 17.54 ^{ij}	0.15 ± 0.03 ^{bcd}	5.98 ± 1.71 ^c	0.117 ± 0.056 ^b	3.39 ± 1.12 ^{ab}
	28	62.97 ± 14.16 ^{gh}	0.12 ± 0.02 ^{cdefg}	6.71 ± 0.99 ^{bc}	0.117 ± 0.0093 ^b	2.79 ± 0.006 ^{abcd}
	42	85.94 ± 3.64 ^{def}	0.06 ± 0.006 ^{hg}	7.89 ± 3.22 ^{abc}	0.0588 ± 0.029 ^b	2.60 ± 0.003 ^{bcd}
	56	105.50 ± 13.59 ^d	0.05 ± 0.008 ^{gh}	8.60 ± 1.81 ^{abc}	0.005 ± 0.0031 ^b	2.24 ± 0.13 ^{bcd}

Reported values correspond to the mean ± standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$)

was less affected by the freezing conditions. In contrast, Yi and Kerr (2009) reported that faster freezing rates caused higher baked bread firmness.

Addition of xanthan gum reduced the hardness of baked samples due to the effect of gum on dough water-binding capacity. According to Rosell et al. (2001) addition of xanthan gum into dough formulation increased its water absorption, making the bread crumb much softer. The present results were in agreement with those of Hagar (2013). They also concluded that crumb hardness of maize bread reduced by addition of xanthan gum. However, adding xanthan gum to dough formulation led to an increase in cohesiveness and springiness of baked samples while their gumminess decreased (Table 2). Therefore, xanthan gum can repair the texture deterioration caused by frozen storage of dough and decrease the hardness of final product.

Specific volume of baked sweet dough

Specific volume is defined as the volume per unit of weight. High loaf volume is positively correlated with a number of consumer-preferred quality characteristics of baked sample, and is commonly used to identify the quality changes in dough (Sharadanant and Khan 2003).

As shown in Fig. 1b, the specific volume of baked sample significantly decreased ($p < 0.05$) with prolonged frozen storage of dough. This decrease in specific volume of baked sample has been attributed to the weakening effect of ice crystals on gluten network during frozen storage. The weakened gluten network led to poor gas retention and a reduction in baked sample specific volume (Hua-Neng et al. 2009).

Addition of xanthan gum to dough formulation improved the final bread specific volume. This result was expected due to the well-known water holding capacity of xanthan gum. A linear correlation was also found between WHC of frozen dough and bread specific volume (Fig. 1c). Therefore, any increase in WHC of frozen dough, increased the specific volume of the final product ($R^2 = 0.77$, $p < 0.05$). As mentioned by other researchers, bread specific volume is strongly influenced by the amount of liquid released from the frozen dough during thawing (Vania and Weibiao 2007).

Xanthan gum can strengthen the dough by forming a strong interaction with flour proteins (Vania and Weibiao 2007). This gum increased the water absorption and the ability of dough to retain gas (Rosell et al. 2001). As a result, the specific volume of the final product and its water activity increased. Mandala (2005) also reported that the addition of xanthan gum into frozen dough formulation led to an increase in bread specific volume. Increase in specific volume of breads by adding hydrocolloids such as sodium alginate, κ -carrageenan, xanthan gum and hydroxyl propyl methyl cellulose was also reported by Rosell et al. (2001).

Furthermore, increase in the rate of freezing improved the specific volume of the final product. During fast freezing, small ice crystals are formed and hence no rupture in the gluten network occurs. Therefore, lower water will be released after thawing the frozen dough and as a result, the specific volume of final bread increases (Hua-Neng et al. 2009).

Among samples, specific volume of baked bread from fast frozen dough containing xanthan gum was higher than other samples. This means that the addition of xanthan into frozen dough formulation can help to minimize the negative effects of frozen storage time on bread specific volume.

Thermal analysis of fresh and frozen sweet dough

The physical state of frozen sweet doughs during freezing or frozen storage may affect dough quality. Therefore, it is important to understand the phase and state transitions (including glass transition) occur in sweet dough at sub-zero temperatures. It has been suggested that the glass transition of frozen dough and its components may affect the stability of dough, as the glass transition may control the rates of recrystallization of ice and diffusion-controlled reactions (Meziani et al. 2012). In this paper, T_g , T_m and amount of freezable water (FW) and unfreezable water (UFW) of frozen sweet dough in the presence or absence of xanthan gum during fast or slow freezing were assessed. As shown in Table 3, the phase transition temperatures were between -37 °C and -39 °C for fresh and frozen dough. At this temperature, dough is close to its glassy state, thermodynamically unstable and a low energy intake can destabilize and eventually promote the recrystallization of water (Meziani et al. 2012). Addition of xanthan gum

Table 3 Measured T_g and T_m by DSC for frozen (or fresh) sweet dough (with fast or slow freezing/with xanthan or without xanthan)

Sample name	T_g (°C)	$T_{m,(onset)}$ (°C)	T_{peak} (°C)	T_{endset} (°C)
With xanthan/with slow freezing	−39	87.91	102.18	125.79
Without xanthan/with slow freezing	−39	90.01	102.98	126.43
With xanthan/with fast freezing	−38	89.97	104.2	124.15
Without xanthan/with fast freezing	−39	84.95	105.06	125.77
With xanthan/fresh sample	−36	87.60	102.4	102.90
Without xanthan/fresh sample	−37	88.82	104.11	124.99

reduced T_{endset} of fresh sweet dough. For fast frozen doughs, the onset of water melting transition (T_{Monset}) slightly increased with addition of xanthan gum. While, adding xanthan gum decreased the T_{Monset} for fresh doughs and slow frozen dough. Furthermore, the final temperature of the transition peak for all doughs slightly decreased with addition of xanthan gum. Therefore the range over which the transition occur was somehow similar to those of fresh dough. These results were similar to those reported by Simmons et al. (2012), who also conclude that a phase transition was present in both soy and wheat dough near 110–120 °C, which has previously been associated with the melting of amylose crystals.

According to Simmons et al. (2012) addition of CMC did not show a significant effect on T_g , Laaksonen and Roos (2000) concluded that the glass transition temperatures (T_g) of frozen wheat dough were between −30 °C and −43.5 °C, depending on the flour used. Rasanen et al. (1998) also reported that the glass transition temperatures (T_g) of frozen dough was less than −30 °C. According to Meziani et al. (2012) the difference between the observed values (for T_g) reported by researchers could have been resulted from the use of different recipes. For example sugar, salt and butter have a great effect on freezing properties and decrease the freezing point. For frozen dough containing xanthan gum, the T_g of samples increased by increasing the freezing rate but T_g of samples without xanthan gum did not change by the rate of freezing (Table 3). Moreover, prolonged storage at temperatures near the glassy state can expose the sweet dough to a maximum cryoconcentration effect (maximum dehydration of the matrix, because most of the water is frozen around T_g) (Meziani et al. 2012). This phenomenon is amplified by the water diffusion into ice crystals (Meziani et al. 2012). Various studies revealed the effect of freezing temperature above the glass transition temperature accelerated the starch retrogradation, therefore increasing the frozen dough hardness (Charoenrein and Preechathamwong 2010). The storage temperature of sweet dough in our study was lower than its glass transition temperature. As a result cryoconcentration effect, water diffusion into ice crystals and starch retrogradation were low.

As shown in Fig. 2 the freezable water (FW) decreased in both types of fast and slow frozen sweet doughs containing xanthan (Fig. 2) while this difference was not significant. The amount of UFW increased with addition of xanthan gum. Furthermore, the FW of frozen dough were greater than those of fresh dough. In a study by Simmons et al. (2012), the amount of FW increased in soy and wheat doughs when frozen storage time increased. The reason of this phenoma was water migration from starch and protein to ice crystals. Bhattacharya et al. (2003) concluded that freezable water freezed when prone to frozen storage,

Fig. 2 The percent of the total moisture content that is FW and UFW in sweet dough. FW is black, UFW is blue (1 fresh sample/without xanthan, 2 fresh sample/with xanthan, 3 fast freezed sample/without xanthan, 4 fast freezed sample/with xanthan, 5 slow freezed sample/without xanthan, 6 slow freezed sample/with xanthan) (color figure online)

which loosen the ability of its binding to gluten during dough formation.

Conclusion

The influence of frozen storage time, xanthan gum and freezing rate on frozen sweet dough were studied. Frozen storage time had negative effect on dough's viscoelasticity (relative residual force, K_1 and K_2). Frozen storage had negative effect on dough quality and as a result bread texture deteriorated with dough frozen storage.

The present study revealed that frozen sweet dough could be made by addition of xanthan gum. Xanthan gum improved the WHC and rheological characteristics of dough which was suitable for bread making. Therefore, xanthan gum can repair the bread texture deterioration caused by frozen storage of dough and decrease the hardness of final product. Furthermore, DSC test revealed that addition of xanthan gum improved the amount of UFW. Bread quality improved with increased rate of freezing. The highest improvement in texture of bread was brought about by fast freezing.

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