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Effect of fructo-oligosaccharide and isomalto-oligosaccharide addition on baking quality of frozen dough

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ABSTRACT

The baking quality of frozen doughs containing different levels of fructo-oligosaccharides (FO) or isomalto-oligosaccharides (IMO) (3–9%, w/w flour), and stored for 0–8 weeks at −18 °C, was examined. The addition of FO or IMO increased the proof volume of the dough and the loaf volume of bread prepared from frozen dough. A 6% addition of FO or IMO was optimum, giving the highest proof volume and bread loaf volume, but a higher concentration than 6% induced low baking quality including lower proof volume and bread loaf volume. The bread crumb was moister and softer after the addition of FO or IMO before, and even after, frozen storage. Darker crumb colour was observed in the bread after the addition of FO or IMO. The oligosaccharides added to the frozen dough were effective in improving the quality of bread made from frozen dough, except for resulting in a darker bread crumb.

1. Introduction

Prebiotics are defined as "nondigestible food components that beneficially affect the host by selectively stimulating the growth and/or activity of a limited number of bacteria in the colon" (Gibson & Roberfroid, 1995). Physiological effects of prebiotics include selective stimulation of the growth of endogenous colonic microbiota, production of lactic and short-chain carboxylic acids as fermentation end products, improvement of mineral absorption (calcium and magnesium) and modulation of lipid metabolism via fermentation products (Roberfroid, 2000). A food ingredient such as fructo-oligosaccharides (FO) can be classified as a prebiotic (Gibson, Probert, Van Loo, Rastall, & Roberfroid, 2004).

A fructo-oligosaccharide is an oligosaccharide of D-fructose residues attached by β-(2 → 1) linkages with a terminal α(1 → 2) linked D-glucopyranosyl that can be produced by the degradation of inulin or enzymatic transfructosylation of sucrose (Yun, 1996). The caloric value of FO is lower than that of other carbohydrates since human intestinal enzymes are incapable of digesting their β-(2 → 1) linkages. As a dietary fibre, fructo-oligosaccharides are effective in improving the intestinal function by increasing stool frequency/weight, and the blood lipid parameters by decreasing serum triglycerides and blood cholesterol levels (Gibson, Beatty, Wang, & Cummings, 1995). As a prebiotic, fructo-oligosaccharides stimulate the growth of beneficial intestinal bacteria such as *Bifidobacteria*, which inhibit the growth of harmful bacteria, stimulate components of the immune system, improve the absorption of certain ions and aid the synthesis of B vitamins (Djouzi & Andlueux, 1997; Gibson et al., 1995). It has also been applied as an ingredient in many food products to improve taste and texture by affording crispiness, increasing expansion of extruded snacks and cereals, and maintaining moisture and freshness of breads and cakes (Franck & Coussement, 1997). When fructo-oligosaccharides were applied to baked goods and breads at 2–25% (w/w), not only was moisture retention improved but they also acted as a sugar replacement (Franck, 2002). With both physiological benefits and physical functions, fructo-oligosaccharides have been applied to numerous foods such as dairy products, frozen desserts, table spreads, baked goods, breakfast cereals, fillings, fruit preparations, salad-dressings, meat products, chocolate and tablets (Franck, 2002).

Another interesting type of oligosaccharide is isomalto-oligosaccharide (IMO) which mainly consists of α-D-glucose residues linked by α-(1 → 6) glycosidic bonds. IMO is typically produced from starch by the treatment of multi-enzymes. For example, maltose produced by hydrolyzing starch using both α-amylase and β-amylase is subsequently converted into isomalto-oligosaccharides by transglucosylation using α-glucosidase (Crittenden & Playne, 1996). Isomalto-oligosaccharides are digested slowly in the jejunum due to the α-(1 → 6) glycosidic linkages and may be fermented by intestinal microflora. Although some studies have demonstrated their prebiotic function,

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isomalto-oligosaccharides have not yet been officially classified as a prebiotic (Gibson et al., 2004).

Currently, frozen dough is commonly used in the baking of fresh bread. By freezing dough, baking can be performed quickly on-demand at an affordable price (Giannou, Kessoglou, & Tzia, 2003). However, bread produced from frozen dough has several problems including gradual loss of dough strength, decreased retention capacity of CO_2, longer fermentation time, and reduced yeast viability and activity. Moreover, decreased loaf volume and deterioration in texture of the final product by using frozen dough have also been reported (Selomulyo & Zhou, 2007). To overcome these problems, manipulation of processing parameters such as mixing time, freezing rate, storage duration and thawing rate has been attempted (Inoue & Bushuk, 1991; Rouillé, Le Bail, & Courcoux, 2000). Also, additives such as emulsifiers and hydrocolloids in dough formulation have also been used to strengthen the dough matrix and increase gas pressure (Ribotta, Pérez, León, & Añón, 2004; Selomulyo & Zhou, 2007).

Although several studies have demonstrated that small sugars and oligosaccharides improve the quality of bakery products such as breads, pastries and cookies, no study has reported the effects of oligosaccharide on the baking quality of frozen dough. In this study, different amounts of fructo-oligosaccharides or isomalto-oligosaccharides were added to frozen dough formulation and their effects on baking qualities such as dough proofing and bread texture were examined.

2. Materials and methods

2.1. Materials

Fructo-oligosaccharides were purchased from CJ Cheil-Jedang Corporation (Seoul, Korea). Isomalto-oligosaccharides and wheat flour were provided by DaeSang Corporation (Seoul, Korea).

2.2. Pasting viscosity

The pasting viscosity of wheat flour, with or without FO or IMO, was determined using an Amylograph (C. W. Brabender Instruments, Inc., South Hackensack, NJ). FO or IMO was used to replace wheat flour at substitution levels of 3, 6 and 9%. The wheat flour dispersion (10% solids, w/w) was heated at a rate of 1.5 °C/min from 30 to 95 °C, held at 95 °C for 15 min, and cooled at a rate of 1.5 °C/min to 50 °C.

2.3. Dough formulation

The dough formulation consisted of wheat flour (200 g), FO or IMO (6, 12, or 18 g), salt (4 g), sugar (12 g), non-fat dry milk (6 g), vegetable shortening (8 g) and yeast (6 g). The same amount of water (124 mL) was added to each formulation. All ingredients except for the shortening were mixed at a low speed (180 rpm) for 2 min and at a medium speed (273 rpm) for 2 min using a vertical mixer (CM12A, Dynasty Co., Taiwan). After addition of the shortening, the dough was continually mixed at the low speed (180 rpm) for 2 min and at the medium speed (273 rpm) for 7 min. Dough temperature during mixing was maintained at 22 ± 2 °C.

2.4. Preparation of frozen dough

The dough was divided and rounded into 110 g pieces, and then the pieces were put into polyethylene bags and frozen by storing in a deep-freezer (CS10, Hengel, France) at −40 °C for 40 min. Storage was continued at −18 °C for up to 8 weeks in a freezer. Frozen dough stored for 2 h at −18 °C was considered as 0 week storage. At different periods of frozen storage (0, 2, 4, 8 weeks), the dough pieces were thawed by leaving them at 6 °C for 24 h, and then at room temperature until the temperature of the centre of dough reached 18 °C.

2.5. Proof volume measurement

The thawed dough pieces were divided into 12 g pieces, and then three pieces were fermented at 35 °C and 85% RH for 90 min in 250 mL mass-cylinder to measure the proof volume (Pyler, 1979).

2.6. Baking properties

The thawed dough was moulded, panned and then proofed at 35 °C and 85% RH for 50 min. After final proofing, the dough was baked at 185 °C for 25 min. Bread loaf volume, moisture content and hardness of bread crumb were measured after cooling at room temperature for 90 min. Bread loaf volume was evaluated using a Volscan Profiler (VSP 600, Stable Micro System, Surrey, UK). Moisture content was measured using slices (15 mm × 15 mm) taken from the centre of the loaf using a moisture analyzer (HB43-S, Mettler-Toledo, Greifensee, Switzerland). A texture analyzer (TA-XT2, Stable Micro Systems, Haslemeres, UK) with a cylindrical probe of 25 mm diameter was used to analyze hardness of the fresh bread crumb. Slices of bread (15 mm thick) obtained from the centre of the loaf were compressed twice to 10 mm distance at a speed of 1.0 mm/s. Colour of bread crumb was measured using a chromameter (CR 300, Minolta, Osaka, Japan). The chromameter probe was placed on the central part of each slice of bread to obtain L^*, a^*, and b^* values.

2.7. Statistical analysis

All experiments were conducted in triplicate and statistical analyses of the data were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Experimental data was analyzed using Tukey's studentized range (HSD) test to determine differences between experimental mean values. The data were assessed by least significant difference at $p < 0.05$.

3. Results and discussion

3.1. Pasting characteristics

Pasting characteristics including pasting temperature, peak viscosity, breakdown and setback of aqueous dispersions of wheat flour containing different amounts (0–9%, w/w based on total solids) of fructo-oligosaccharides or isomalto-oligosaccharides are summarized in Table 1. The addition of FO increased pasting

Table 1
Pasting properties of wheat flour containing different amounts of fructo-oligosaccharide (FO) or isomalto-oligosaccharide (IMO) (0–9%).[1]

	Pasting temp. (°C)	Peak viscosity (BU)	Breakdown (BU)	Setback (BU)
Flour	61.7 ± 0.2^{c}	579 ± 22^{a}	165 ± 8^{a}	374 ± 8^{a}
Flour + 3% FO	62.5 ± 0.4^{b}	528 ± 15^{b}	141 ± 7^{b}	342 ± 3^{b}
Flour + 6% FO	62.3 ± 0.2^{bc}	468 ± 17^{c}	123 ± 2^{c}	305 ± 4^{cd}
Flour + 9% FO	63.5 ± 0.1^{a}	406 ± 8^{d}	95 ± 4^{d}	275 ± 5^{e}
Flour + 3% IMO	61.9 ± 0.3^{bc}	543 ± 16^{ab}	155 ± 3^{ab}	344 ± 5^{b}
Flour + 6% IMO	62.5 ± 0.4^{b}	472 ± 12^{c}	124 ± 9^{c}	319 ± 8^{c}
Flour + 9% IMO	62.1 ± 0.2^{bc}	413 ± 6^{d}	156 ± 2^{ab}	294 ± 9^{d}

[1] Data followed by different letters within a column are significantly different ($p < 0.05$).

temperature and decreased peak viscosity, breakdown and setback proportionally with the concentration of FO. When IMO was added, peak viscosity and setback were significantly decreased whereas pasting temperature slightly increased or did not change. The breakdown decreased as the IMO concentration increased up to 6%; however, it increased when the concentration increased to 9%. Overall, FO addition induced more significant changes in pasting characteristics than IMO addition. Rodriguez-Sandoval, Franco, and Manjarres-Pinzon (2014) reported similar results for cassava starch mixed with FO, in which pasting temperature was increased but peak viscosity, breakdown and setback were decreased by FO addition (9–29%). Increased pasting temperature and decreased peak viscosity indicate that the oligosaccharides inhibited the swelling of starch granules and delayed the formation of viscous paste during heating. Considering that oligosaccharides may possess a higher capacity to interact with water than starch, their addition could lower the amount of available water for pasting of starch (Angioloni & Collar, 2009; Spies & Hoseney, 1982). Also, the lowering of starch portion by increasing the concentration of FO or IMO might contribute to decreased overall pasting viscosity, because FO or IMO can replace wheat flour in the dispersion. Setback is the rise of viscosity by the re-association of solubilized amylose and amylopectin polymers during the cooling phase, which represents the tendency of starch retrogradation and staling of bread. The decreased setback caused by the addition of FO or IMO indicates that the oligosaccharides were effective at retarding the starch retrogradation and bread staling during storage. A study by Katsuta, Nishimura, and Miura (1992) reported that addition of malto-oligosaccharides decreased retrogradation in rice starch gels.

3.2. Proof volume of dough

Proof volume of dough frozen for different periods (0–8 weeks) are presented in Fig. 1. Proof volume from frozen dough decreased as the frozen storage period increased up to 8 weeks. The addition of FO or IMO increased the proof volume of frozen dough compared to the control stored for same period except in the case of 9% FO or IMO stored for 8 weeks. The addition of 9% FO or IMO resulted in the highest proof volume after 2 or 4 weeks storage, and the addition of 3% or 6% of FO or IMO was also effective in increasing the proof volume. However, the proof volume of the dough containing 9% FO or IMO rapidly decreased when the storage was extended to 8 weeks, resulting in the lowest value among the samples. A decrease of proof volume has previously been observed when inulin was added to dough (Peressini & Sensidoni, 2009; Wang, Rosell, & Benedito de Barber, 2002). Inulin decreased dough volume and expansion, which was explained by the increases in elasticity and solid-like behaviours resulting from interaction between inulin and the gluten network. Likewise the decrease in proof volume caused by the larger concentration (9%) of FO or IMO and the long frozen storage (8 weeks) might result from the interaction of the oligosaccharides with the gluten network in dough, which was facilitated by extending the frozen storage. It is widely known that the frozen storage of dough causes the deterioration of dough quality by low gassing power due to a decline in both viability and activity of yeast and by the loss of dough strength (Ribotta et al., 2004). The release of reducing substances from dead yeast cells contributes to the reduction of gluten cross-linking resulting in the loss of dough strength (Giannou et al., 2003). Moreover, ice formation may disrupt the gluten matrix and lead to a less continuous but more ruptured and separated network of starch granules (Berglund, Shelton, & Freeman, 1991). In particular, the formation of large ice crystals during recrystallization contributes to the damage of starch granules and decreases the ability of gluten to retain gas during proofing (Selomulyo & Zhou, 2007). Finally, another study showed that the negative effect from ice formation and growth became increasingly severe as the storage period increased (Lu & Grant, 1999).

Overall, the experimental data revealed that the addition of FO or IMO retarded the decrease of proof volume by minimizing the damages induced by freezing. Therefore, oligosaccharide addition contributed to improving the gas retention during proofing of frozen dough. It was hypothesized that the ice formation and growth had been effectively hindered by the presence of oligosaccharides because of their strong affinity to water in dough. Also, oligosaccharides themselves may directly affect the physical properties of dough through interaction with gluten. When the frozen storage was longer, however, a higher concentration of FO and IMO may have induced adverse effects caused by freezing as shown for 9% FO and IMO.

3.3. Moisture content of bread

Fig. 2 represents the moisture content of bread crumb made from the frozen dough stored for different periods (0–8 weeks). Increased storage period resulted in decreased moisture content of bread containing no FO or IMO, indicating loss of water during

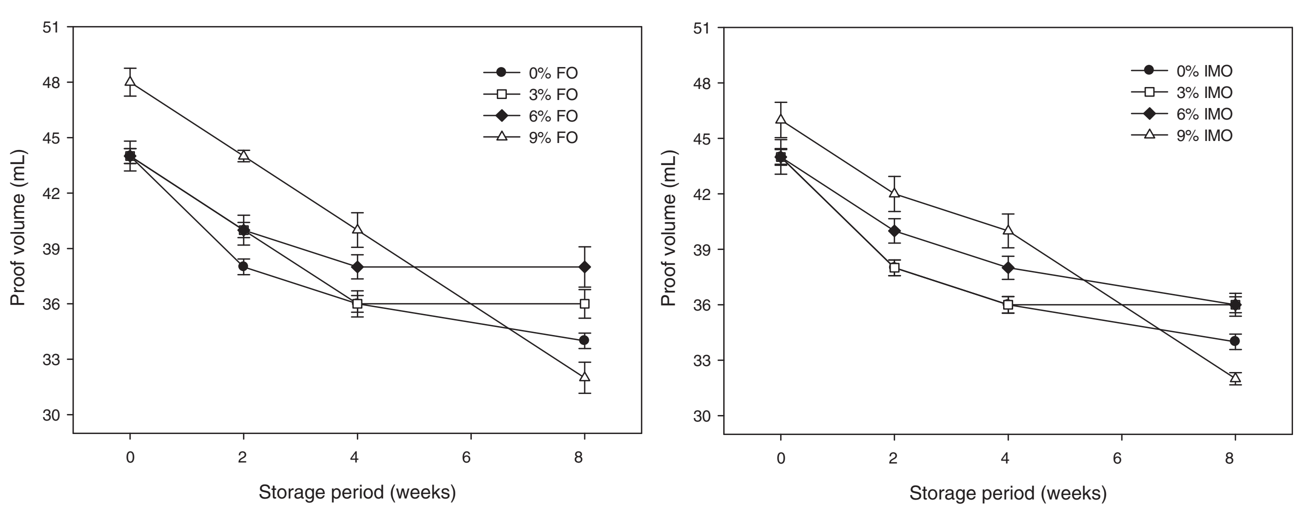

Fig. 1. The change of proof volume of dough containing fructo-oligosaccharides (FO) or isomalto-oligosaccharides (IMO) during storage of frozen dough for 0, 2, 4 and 8 weeks.

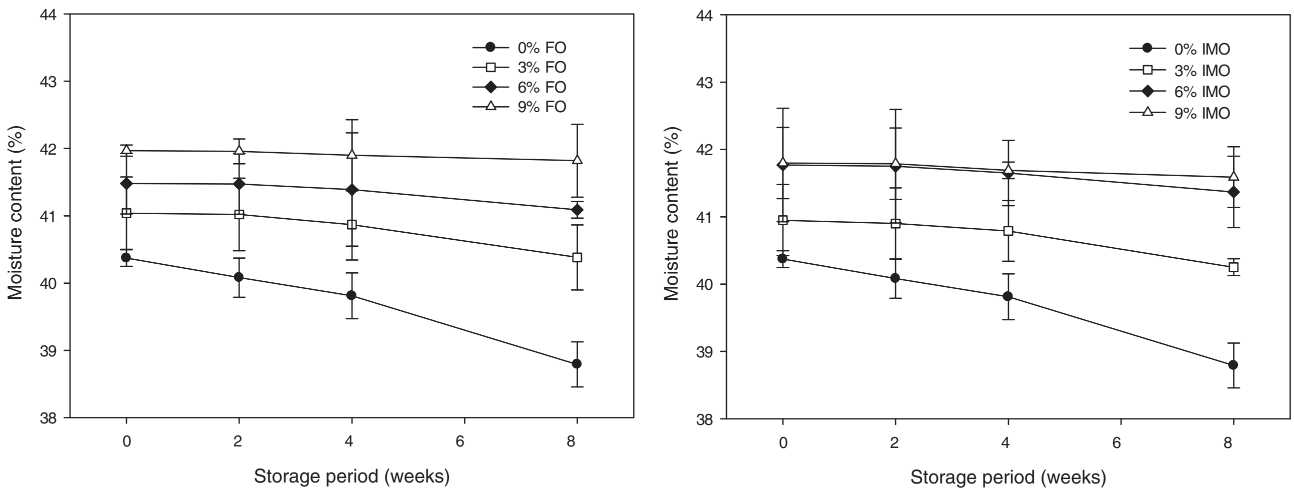

Fig. 2. The change of moisture content in bread made from frozen dough containing fructo-oligosaccharides (FO) or isomalto-oligosaccharides (IMO) during storage of frozen dough for 0, 2, 4 and 8 weeks.

the frozen storage of dough. The addition of FO or IMO in dough, however, resulted in higher water retention in the bread than the control containing no oligosaccharides (Fig. 2). Water retention is favoured, because it maintains the freshness and soft texture of the bread crumb. It was supposed that increased water retention resulted from the high affinity of the oligosaccharides to water (Crittenden & Playne, 1996). Also, increased moisture contents of crumb were observed in breads containing 8% and 10% of FO (Praznik, Cieslik, & Filipiak-Florkiewicz, 2002). However, decreased moisture content of bread via FO addition have also been reported by Peressini and Sensidoni (2009). Differences in the amount of water during dough preparation may partially explain such contradictory results. Peressini and Sensidoni (2009) used a lower amount of water for dough preparation when FO was added, whereas the dough in the current study was prepared with a constant amount of water.

3.4. Bread loaf volume

Loaf volumes of the bread prepared from frozen dough of different oligosaccharide concentrations and storage periods are shown in Fig. 3. The loaf volume of the bread slightly decreased with increased storage time for up to 8 weeks; however, the addition of FO or IMO induced a much higher loaf volume of bread than the control. Higher loaf volume of bread containing added FO or IMO was observed after the frozen storage from 0 to 8 weeks. In particular, 6% addition of FO or IMO showed the highest loaf volume. It is noticeable that loaf volume of bread containing 9% FO or IMO was lower than that containing 3% and 6% FO or IMO. Giannou and Tzia (2007) reported that dough deterioration severely occurs during the first steps of freezing due to thermal shock in yeast cells and to the gluten network. In this study, FO and IMO addition may protect frozen dough from the damage by initial freezing.

The delay of starch gelatinization by oligosaccharide addition (Table 1) might change the role of starch during baking, resulting in changes of baking quality. Peressini and Sensidoni (2009) reported that inulin addition delayed starch gelatinization in wheat flour, which might promote dough expansion during baking and result in increased bread loaf volume. Also, as shown in Fig. 1, the increased proof volume and improved gas retention by the FO or IMO addition might be associated with the positive effect on bread loaf volume.

The amount of liquid released from the frozen dough during thawing largely influenced loaf volume of bread made from frozen dough (Selomulyo & Zhou, 2007). Seguchi, Nikaidoo, and Morimoto

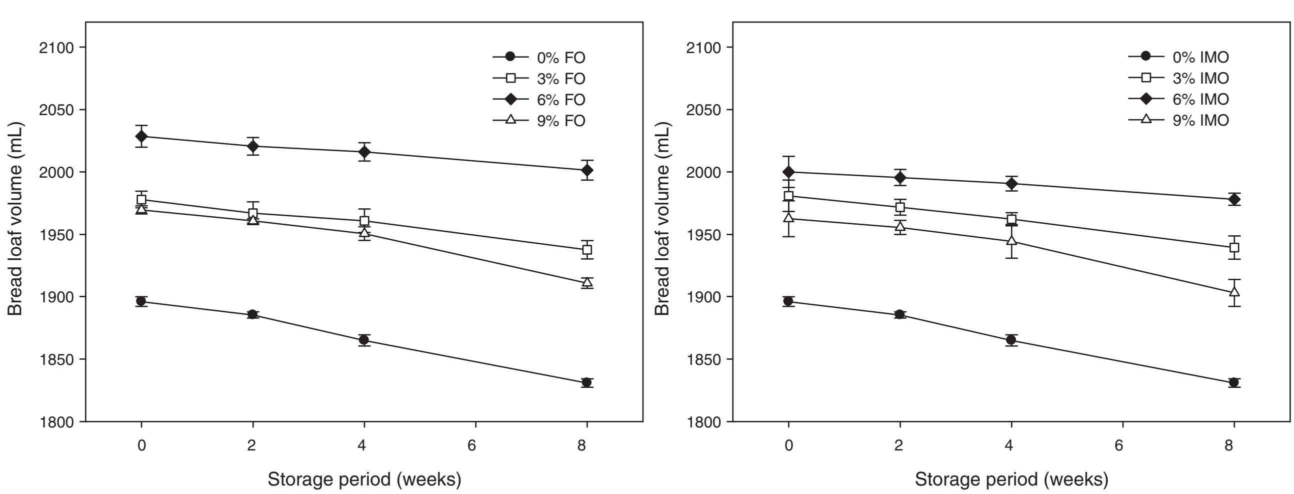

Fig. 3. The change of bread loaf volume of bread made from frozen dough containing fructo-oligosaccharides (FO) or isomalto-oligosaccharides (IMO) during storage of frozen dough for 0, 2, 4 and 8 weeks.

(2003) found a strong inverse correlation between the amount of liquid that oozed from the dough and its breadmaking properties. High loaf volume and low firmness of bread was observed in bread that contained hydrocolloids with high water retention capacity (Selomulyo & Zhou, 2007). Increased water affinity caused by the addition of FO and IMO could be associated with the increased bread loaf volume of bread made from non-stored frozen dough and frozen dough stored for up to 8 weeks.

3.5. Hardness of bread crumb

The bread containing 0% FO or IMO became harder as the storage period for the frozen dough increased (Fig. 4). The addition of FO or IMO to the dough retarded hardening of the bread. Prior to frozen storage (0 week in Fig. 4), FO or IMO addition itself made the bread softer and the soft texture of the bread was maintained after frozen storage for up to 8 weeks. Soft crumb texture of bread containing FO or IMO might be partially due to large loaf volume and high moisture content of bread. Similarly, decrease in bread crumb hardness was observed when inulin was added (Peressini & Sensidoni, 2009)).

The arrangement of polymeric components in dough might be affected by the changes in water mobility and ice formation during frozen storage (Selomulyo & Zhou, 2007). It was reported that starch retrogradation occurred faster in the aged bread made from frozen dough than in bread made from non-frozen dough (Ribotta, León, & Añón, 2003). In particular, amylose, which is a determining factor for initial loaf firmness (Goesaert et al., 2005), might be rearranged in the dough matrix during frozen storage in a manner that makes it ready to associate after baking, resulting in the increased hardness of bread. FO and IMO added to the frozen dough retarded this undesirable change of polymeric rearrangement, possibly by inhibiting ice formation and assisting in the dough proofing. This positive effect of oligosaccharide addition became more significant when the dough storage period was longer. Therefore, the addition of FO and IMO stabilized the frozen dough against the hardening effect induced by freezing, and thus assisted the bread in remaining soft even after a lengthy storage of frozen dough.

3.6. Colour of bread crumb

L*, a*, and b* values of bread crumb are shown in Fig. 5 to determine colour of bread containing FO. The colour of bread containing IMO is not shown in this figure, but the trend of crumb colour was similar. When FO was added, the L* value of the bread crumb decreased. Notably, 6% addition of FO induced the lowest L* value of bread crumb. Breads containing FO were generally darker when compared to control. A 3, 6, or 9% concentration of FO induced a higher a* value (−value) and lower b* value (+value) than control, indicating less greenish and less yellowish colour. It was also noteworthy that the L* value decreased as the frozen storage period increased, regardless of the presence of FO and IMO. Similarly, Giannou and Tzia (2007) and Sharadanant and Khan (2003) reported that the darkness of bread crumb increased after/due to

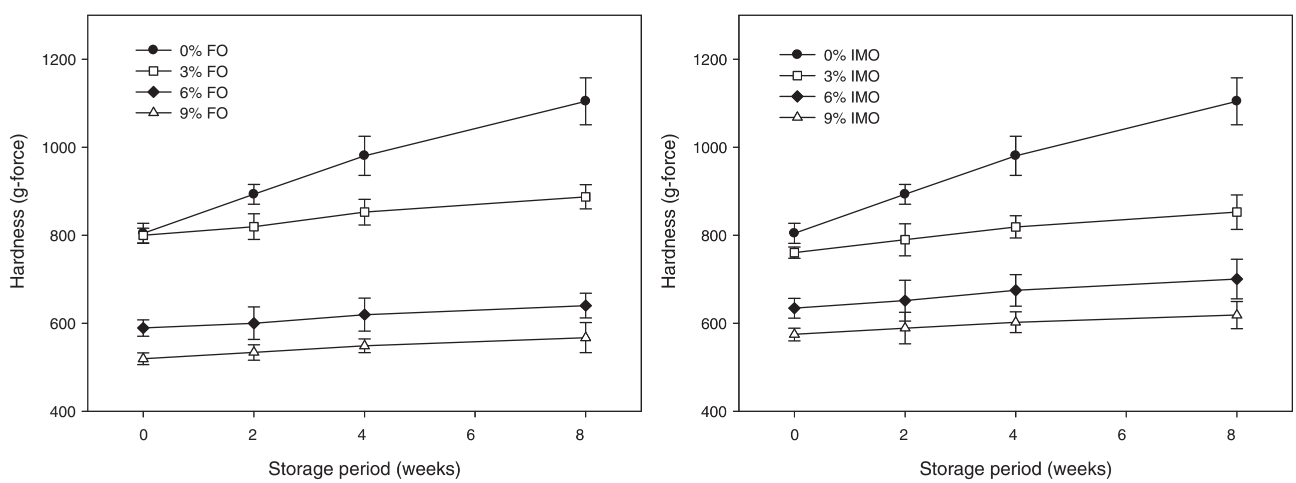

Fig. 4. The change of hardness of bread made from frozen dough containing fructo-oligosaccharides (FO) or isomalto-oligosaccharides (IMO) during storage of frozen dough for 0, 2, 4 and 8 weeks.

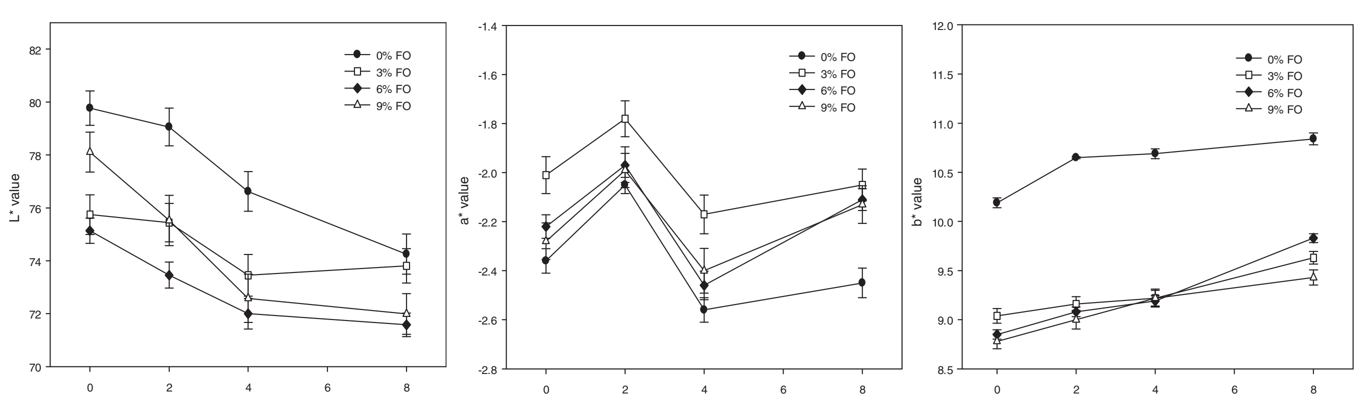

Fig. 5. The colour of bread crumb made from frozen dough containing fructo-oligosaccharides (FO) stored for 0, 2, 4 and 8 weeks.

the frozen storage. The dark colour of bread containing FO or IMO may be expected due to caramelization and the Maillard reaction, which are both highly affected by the reaction of reducing sugars with amino acids (Gallagher, Gormley, & Arendt, 2003). The reduced loaf volume with frozen storage might increase the density of crumb, which could partly contribute to the increased darkness. Also, the release of reducing substances from dead yeast cells during freezing might inhibit oxidation of colour pigments such as carotenoids, resulting in dark bread colour.

4. Conclusion

The addition of FO or IMO to frozen dough improved the baking quality even after frozen storage for up to 8 weeks. The added FO and IMO alleviated deterioration of frozen dough and thus resulted in increases in proof volume, loaf volume of bread and moisture content, and decrease in hardness of bread crumb. However, addition of FO or IMO induced darker bread crumb and darkening was severe when frozen storage was extended up to 8 weeks. The addition of 6% FO or IMO showed the most significant effect on baking quality during the frozen storage from 0 to 8 weeks. However, a larger dose of FO and IMO could have induced adverse changes in frozen dough.

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