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Effect of degree of substitution of carboxymethyl cellulose sodium on the state of water, rheological and baking performance of frozen bread dough

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ABSTRACT

Influence of carboxymethyl cellulose sodium (CMCNa) with different degree of substitution (DS = 0.5, 0.8, and 1.1) on water distribution, rheological property, microstructure, and baking performance of frozen bread dough were studied during frozen storage. Results revealed that addition of CMCNa slowed the increase of freezable water content and tanδ of dough during frozen storage, and CMCNa with high DS had more beneficial effects on inhibition the change of freezable water content and tanδ. The CMCNa weakened the influence of the frozen treatment on the water mobility and stabilized the microstructure. The bread made from frozen dough possessed larger specific volume and smaller hardness with addition of CMCNa. And the high DS CMCNa showed the most positive effect on baking quality of frozen dough during the frozen storage from 0 to 8 weeks.

1. Introduction

Frozen bread dough is commonly used in the baking of fresh bread. The dough can be manufactured on a large scale, and then shipped to local restaurants or retail operations for on-site baking. It has been extensively studied in recent years because it has advantages such as saving time, space, equipment and retailing expenses (Giannou & Tzia, 2007). But there are several problems arising from the production of bread made from frozen dough such as: decrease in the retention capacity of CO_2; gradual loss of the dough strength; longer fermentation time; lowering of loaf volume; reduced yeast activity; and deterioration in the texture of the final product (Selomulyo & Zhou, 2007). During frozen storage, the water separates from the gluten because of temperature fluctuations and crystallizes. Crystals growing inside the pores causes serious damage to the gluten-starch structure that can account for the poor baking performance of frozen dough (Esselink, van Aalst, Maliepaard, & van Duynhoven, 2003).

Hydrocolloids can soften texture, enhance bread volume and lead to lower staling rates. Moreover, they can reduce the physical damage induced by ice crystals in breads obtained from frozen dough or partially baked frozen bread (Bárcenas & Rosell, 2006). Addition of guar and xanthan reduced the amount of freezable water and consequently reduced the fusion enthalpy (Matuda, Chevallier, de Alcântara Pessôa Filho, LeBail, & Tadini, 2008). Addition of fructo-oligosaccharides and isomalto-oligosaccharides increased the proof volume of the dough and the loaf volume of bread prepared from frozen dough (Park, Jang, & Lim, 2016). With increasing amounts of damaged starch to frozen dough, pasting temperatures increased, but peak viscosity, low viscosity, breakdown, final viscosity and setback increased and then decreased (Ma et al., 2016). It has been proved that hydroxylpropyl methyl cellulose (HPMC) could stabilize gluten network and retard the transition of water status from the unfreezable to the freezable so as to lower the amount and size of ice crystals (Xuan et al., 2017).

Carboxymethyl cellulose sodium (CMCNa) is a typical anionic polysaccharide and is the most crucial water-soluble derivative of cellulose that is formed by its reaction with sodium hydroxide and chloroacetic acid (Biswal & Singh, 2004). It has been widely used as a thickener and stabilizer in food industry. The average degree of substitution (DS) of CMCNa is defined as the average number of carboxymethyl groups per repeating unit and the maximum DS in

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theory is 3. While more typically DS is in the range of 0.6–0.95 for food applications (Coffey, Bell, & Henderson, 2006). CMCNa with high DS could increase the electrostatic repulsion between protein particles, which prevented the phase separation in the acidified milk drinks (Du et al., 2009).

Addition of CMCNa has been proved to improve loaf volume, external and internal appearance, and also bread firmness of bread compared with bread prepared by the frozen dough without CMCNa (Sharadanant & Khan, 2003). Ngemakwe, Le Roes-Hill, and Jideani (2015), investigated the effect of CMCNa on the mixing properties of oat dough, and the results showed that CMCNa significantly increased stability, energy at peak, development and departure times, but significantly decreased water absorption, peak resistance, softening and bandwidth at peak.

Although many studies have proved that the addition of CMCNa could improve the quality of frozen dough, there are rare reports about the effects of DS of CMCNa on the quality of frozen dough. The objective of this research was to evaluate the effects of degree of substitution of CMCNa on the state of water, rheological and baking performance of frozen bread dough.

2. Materials and methods

2.1. Materials

Commercial bread flour was purchased from Taiyanghua Company (Wuhan, China). The moisture, ash, and protein contents were 10.3%, 0.33%, 13.8%, respectively. Shortening (Fonterra Co-operative Group, New Zealand), yeast (Angel Yeast corp, China), salt and sugar were purchased from a local market in Wuhan. The cellulase was purchased from Jiangsu Ruiyang biotech Corp, China. The activity unit of cellulase was 50000U/g.

Samples of CMCNa with different degree of substitution were purchased from Aldrich (Sigma-Aldrich). According to the unpublished results in our lab, the molecular weight of CMCNa would influence the property of frozen dough, so it is necessary to keep the same molecular weight of CMCNa. Therefore, the CMCNa with different degree of substitution were hydrolyzed by cellulase until molecular weight was as close as possible. The weight-average molecular weight, dispersity and viscosity of CMCNa dissolved in deionized water with different DS are listed in Table 1. The cellulase was used to degrade CMCNa in the following manner: the cellulase (10U) was added to the aqueous solution of 2% CMCNa at 37 °C. The weight-average molecular weights of hydrolyzed CMCNa were determined according to a previous study (Karlsson et al., 2002) with some modifications by gel permeation chromatography with on-line multi-angle laser light scattering (GPC-MALLS, Wyatt Technology Corporation). Sample solution (0.1% w/w) was injected into the system at 1 mL. Sodium nitrate solution 50 mM with 0.02% w/v sodium azide was used as mobile phase at a flow rate of 0.3 mL/min and 25 °C.

Because the hydrolysis may change the DS of CMCNa, the degree of substitution of the prepared CMCNa samples was adopted from GB/T 1904–2005. The sample (1.5 g) was washed by ethyl alcohol for several times until the filtrate was in red after added a drop of K_2CrO_4 solution and $AgNO_3$ solution, and then dried at 120 °C for 2 h. Next, the sample was removed to Muffle furnace at 700 °C for 15 min. Then, 100 ml of distilled water and 50 ml of 0.1 M H_2SO_4 were added so that the CMCNa was in the free acid form. The degree of substitution of CMCNa was determined by titration of the free acid with sodium hydroxide. The results of DS were 0.5, 0.8, and 1.1, respectively.

The apparent viscosity of CMCNa solutions was measured by a Brookfield Viscometer DV-II+ pro with the probe Model 61, which is suitable for measuring the viscosity of low-viscous solutions.

Table 1
The weight-average molecular weight (Mw), dispersity (Mw/Mn) and viscosity of CMCNa dissolved in deionized water with different DS.

Name of CMCNa	DS	Mw (Da)	Mw/Mn	Viscosity (mPa·s)
DS0.5	0.5	1.090×10^5	1.105	31.8 ± 0.66 (2% w/w)
DS0.8	0.8	9.745×10^4	1.256	33.4 ± 1.18 (2% w/w)
DS1.1	1.1	9.046×10^4	1.329	30.4 ± 0.89 (2% w/w)

2.2. Dough preparation

Dough was prepared with 100 g flour, 50 g water, 10 g sugar, 2 g compressed yeast, 1 g salt, and 5 g shortening. CMCNa was used to replace wheat flour at substitution levels of 0.5%. As a simplification, these will be referred to DS0.5, DS0.8, and DS1.1 group which indicated the dough with DS of 0.5, 0.8, and 1.1 of CMCNa, respectively. The dough with no CMCNa was set as control group. All ingredients were mixed in a bread machine for 8 min. Then the dough was molded and packed in polyethylene bags, and immediately placed in a deep-freezer (DW-FW110, Zhongke Meiling Cryogenics corp, China) at −30 °C for 2 h, and then stored at −18 °C in a freezer for up to 10 weeks.

2.3. Thawing and preparation of dough for analysis

The dough pieces were thawed at 20 °C for 30 min (80% RH), and then leavened in a fermenting box at 30 °C and 80% RH for 75 min. Dough samples used for baking performance examination were placed into the oven at the temperature of 190 °C for 15 min. The bread samples were allowed to cool at room temperature for 30 min.

2.4. Measurement of freezable water content

The state of dough water was investigated by differential scanning calorimetry (DSC 204F1, Netzsch, Germany). Dough sample (10–20 mg) was placed in a stainless-steel pan then hermetically sealed and immediately scanned in the calorimeter. All scans were administered by equilibrating the samples at −30 °C for 5 min and then subjected to heating at the rate of 4 °C/min up to 10 °C. Nitrogen gas flow of 50 mL/min was used to avoid water condensation in the calorimeter head.

Enthalpy of melting (△Hm) was calculated by software provided by the DSC manufacturer. The freezable water content of the dough (c_{fw}) was calculated with the following formula (Ding et al., 2015):

$$c_{fw}(\%) = \frac{\Delta Hm}{\Delta_{fus}Hm \times W_A} \times 100 \quad (1)$$

Where $\triangle_{fus}$Hm is the known latent heat of fusion of ice, 334 J/g and W_A is the moisture content of the sample, g/g.

2.5. Low field nuclear magnetic resonance (LF-NMR)

Proton relaxation measurements were performed by using a Proton (^{1}H) NMR spectrometer (NMI20-015V-1, Shanghai Niumag Co. Ltd., China) to analyze the T_2 relaxation time. Approximately 2 g dough was wrapped by polytetrafluoroethylene tape to stop the water dry out and placed in a 15 mm diameter glass tube. The dough was thawed at ambient temperature for 1 h. The duration between successive scans (TW), time of echo (TE), number of the scans (NS) and number of echoes (NECH) were 3000 ms, 0.2 ms, 4 and 1000, respectively. The CPMG data were fitted by T_2-fit