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Effect of multiple freezing/thawing-modified wheat starch on dough properties and bread quality using a reconstitution system

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Multiple freezing/thawing-modified starch (FTS)-gluten reconstituted doughs were prepared and dynamic rheological tests of the reconstituted doughs were performed using dynamic frequency sweep modes. The substitution of FTS revealed predominantly elastic characteristics in frequency range from 10^{-1}–10^{1} Hz. It also changed the thermal behavior of starch–gluten mixtures: the more cycles of freezing/thawing treatment the lower the starch-gelatinization enthalpy and the higher the retrogradation enthalpy of amylopectin. The reconstituted dough was baked and stored for 1 week at 4 °C, and analyzed for retrogradation properties. A significant increase ($p < 0.05$) in relative crystallinity was observed on the breadcrumbs baked with FTS (subjected to 10 freezing/thawing cycles). In addition, the firmness of breadcrumb increased with storage time, and multiple freezing/thawing-modified starch (10 FTS) was the highest. The causes of those alterations in the dough did so by altering the water absorption of starch granules after exposure to freezing and thereby decreased the amount of available water for dough formation. The dough properties will be the factors determining the bread retrogradation.

1. Introduction

Over the past few years, the bakery industry has exploited the advantages and applications of freezing technology in several foods and developed a special interest on it in order to save labor and cost (Marston, 1978). However, the use of frozen dough in breadmaking presents several problems. For example, the effect of freezing leads to a loss of bread freshness and a short shelf-life called bread retrogradation (Rosell and Gómez, 2007). It was first suggested by Schoch and French (1947) that bread retrogradation essentially involves the retrogradation of the amylopectin but not the amylose fraction. Since then, many investigations have been carried out to determine the respective role of amylopectin and amylose in the retrogradation of baked products (Gudmundsson, 1994; Hoover, 1995). One of the general accepted theory was that amylose gelation involved a rapid network development, typically less than 1 day, via chain entanglement; while amylopectin was responsible for slow development of the crystallinity in the polymer-rich regions, which might continue for weeks (Sasaki et al., 2000). These changes occurring produced a loss of consumer acceptance, which was one of the most serious challenges for the frozen dough industry (Anon et al., 2004).

Although considerable progress in understanding the retrogradation process occurred, frozen bread retrogradation still remained a non-well-understood phenomenon. Lu and Grant (1999) compared the thermal properties of wheat starches isolated from original wheat flour and frozen doughs after subjecting to 16 weeks of frozen storage. The gelatinization temperature and melting enthalpy of the frozen dough starch were found to be increased with frozen storage time. They reflected the possibility of some retrogradation taking place within the starch granules during frozen storage or perhaps during the thawing of the doughs before starch isolation. A rapid retrogradation was also found by Meziani et al. (2011) who observed an increase in the relative crystallinity

Abbreviations: DSC, differential scanning calorimetry; FTS, freezing/thawing-modified starch; G′, storage modulus; G″, loss modulus; ΔH, gelatinization enthalpy; NWS, native wheat starch; RC, relative crystallinity; T_o, onset temperatures; T_p, peak temperatures; T_c, conclusion temperatures; Tanδ, phase angle; XRD, X-ray Diffraction.

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of sweet dough frozen at different freezing rates. Tao et al. (2016) investigated differences in starch isolated from fresh dough and frozen doughs. A loss of starch integrity and leaching materials were found in the doughs subjecting to multiple freezing/thawing treatment. They further compared the effect of particle size distribution in relation to baking properties of frozen dough, and noted small starch granules were more sensitive to freezing treatment compared with large starch (Tao et al., 2016).

Based on the literature cited above, it is clear that the role of starch and the interactions in the frozen dough have not been studied as extensively as have protein factors. More work is thus necessary to better understand the cause-and-effect relationships between starch and baked frozen dough. In what follows, reconstitution system has been used as a tool for deepening the research. The reconstituted dough can be described as a bicontinuous system, where gluten forms one phase, and starch the other (Larsson and Eliasson, 1997). The addition of purified components could be altered to find which one was responsible for different baking qualities (Goesaert et al., 2008).

Thus, the objectives of the present work were: 1) to study the effect of substitution of wheat starch by freezing-modified starch on rheological and thermal characteristics of dough; 2) to analyze bread retrogradation using a reconstitution system.

2. Materials and methods

2.1. Materials

Wheat starch was purchased from Puluoxing Starch Co., Ltd. (Hangzhou, China). Commercial wheat gluten (crude protein content, 62.1% on a dry basis using 6.25 as the nitrogen/protein conversion factor for gluten proteins) was obtained from Weijing Co., Ltd. (Shanghai, China). Active dry yeast (Angel brand, Hubei, China), sugar, and salt were purchased from a local market in Wuxi, China. All other chemicals and reagents were purchased from Sinopharm Chemical Reagent Co., Ltd. (Suzhou, China) and of analytical grade unless other stated.

2.2. Freezing/thawing treatment

Wheat starch was dispersed in deionized water by stirring at 25 °C for 3 h to produce starch suspensions with a final concentration of 40% (w/w). Then the samples were frozen at −34 °C for 22 h and thawed in water bath at 25 °C for 2 h. This freezing/thawing cycle was repeated for several cycles (3, 7, and 10 respectively) before centrifugation at 2200 × g for 20 min. The starch residues were collected after being freeze-dried with Labconco FreeZone (Labconco, USA). Control samples were stirred at 25 °C for 3 h and then directly centrifuged at the above conditions.

2.3. Preparation of reconstituted dough

The preparation of dough was important for the reproducibility of the results (Graßberger et al., 2003). Therefore, a Brabender Farinograph-E (Brabender, OHG, Duisberg, Germany) was used to mix gluten (48 g), starch samples (258 g) and salt (4.5 g) for 5 min at 63 rpm. Then the mixtures were hydrated with a fixed level of water addition: 58% on total wet basis for 6.5 min, and molded into 60 g dough. The level of water addition and mixing time were determined with farinograph procedure (optimum development peak for dough with native wheat starch). The reconstituted flours consisted of wheat starch and gluten in a ratio of 86/14 calculated on dry basis content. To evaluate the impacts of freezing, the starch fraction in the reconstituted blends was substituted with freezing/thawing-treated starch while the reference was mixed with native one.

2.4. Rheological properties

Rheological measurements were carried out using an AR G2 Rheometer (TA instrument Inc., USA). The frequency sweeps tests were performed on dough discs (50 mm diameter) using rough surface parallel plates (50 mm diameter) with 1 mm gap at 25 °C. Silicon oil was applied to the exposed surfaces of samples to prevent evaporation during experiments. In order to relax the samples before the measurements, all samples were allowed to rest for 15 min. Frequency sweeps tests from 0.1 to 10 Hz were performed at 15 Pa within the linear viscoelastic region. Data for storage modulus (G'), loss modulus (G'') and phase angle ($\tan\delta$) were collected and used to compare the freezing effects.

2.5. Differential scanning calorimetry (DSC)

A SIINT instrument (X- DSC 7000 model, Japan) was used in order to study the thermal transitions of dough samples during cooking process. For comparison, samples containing only gluten, starch, water and salt were run. Samples were weighed onto aluminum DSC pans and then were hermetically sealed. Pans were kept 1 h at 25 °C and then were heated from 30 °C to 90 °C at 10 °C/min (together with an empty reference pan). From thermograms gelatinization enthalpy (ΔH) and onset (T_o), peak (T_p) and conclusion temperatures (T_c) were obtained. After the DSC run, gelatinized dough samples (in the original sealed pan) were stored at 4 °C for 1, 3, 5, and 7 days for retrogradation studies. After prescribed storage, samples were allowed to equilibrate at room temperature for 1 h before being rescanned using DSC with the same heating program. Each sample was run in triplicate to determine the mean value.

2.6. Bread making

Doughs were prepared as described for rheological assays but with incorporation of 1.5% fresh yeast. Dough was divided into 60 g pieces. Each portion was rounded by hand and then kept at 37 °C with 80% relative humidity for 90 min. After fermentation, doughs were baked in a rotary oven (SM-603T, Sinmag Machinery, Wuxi, China) at 210 °C for 15 min. After baking, breads were allowed to cool for 2 h before being packed in polyethylene bags and stored for 1, 3, 5, and 7 days at 4 °C. For each experiment, three replicates from each loaf were made.

2.7. Crumb texture

Slices of bread of 2 cm high were subjected to compression in two cycles using a TA-XT plus analyzer (Perten Instruments, Hägersten, Sweden) with a cylindrical probe of 25 mm diameter. Eight slices of each sample were compressed up to a 50% of strain. A hardness parameter was obtained at a pre-test speed 3 mm/s, test speed 1 mm/s, and post-test speed 5 mm/s. Three replications were performed for each sample.

2.8. X-ray diffraction (XRD)

Bread samples were taken at day 0, 1, 3, 5, and day 7 for XRD studies. The crumb samples were freeze-dried with Labconco FreeZone (Labconco, USA) and then milled in a laboratory mill and passed through a 0.149 mm. X-ray diffraction measurements have been performed in duplicate on a Sidemen's D5005 X-ray diffractometer. The XRD pattern was recorded by a Bruker D8-Advance XRD instrument (Bruker AXS Inc., Karlsruhe, Germany) with nickel-filtered Cu-Kα (wavelength 1.5405 Å) radiation under the conditions of 40 kV and 30 mA. The diffractograms were collected