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The final established physicochemical properties of steamed bread made from frozen dough: Study of the combined effects of gluten polymerization, water content and starch crystallinity on bread firmness

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ABSTRACT

The gluten polymerization behavior, water content, starch crystallinity and firmness of Chinese steamed bread made from frozen dough were investigated and their correlations were also established in this study. The decreased degree of gluten polymerization in steamed bread was observed by the enhanced SDS-extractable proteins (SDSEPs) upon frozen storage. Less incorporation of glutenin in the glutenin −gliadin crosslinking of steamed bread mainly contributed to the decreased degree of gluten polymerization. The decreased moisture of steamed bread had a significant negative correlation with the sublimated water in frozen dough ($r = -0.8850$, $P < 0.01$). Frozen storage also induced an increase in starch crystallinity and bread firmness. A multiple linear regression model with SDS-extractable proteins, water content and melting enthalpy of starch crystals of steamed bread accounted for 86% of the variance in the natural logarithm of firmness and further revealed that starch crystallinity mainly contributed to bread firmness.

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1. Introduction

Chinese steamed bread (CSB) is a traditional Chinese staple food and can be simply formulated by wheat flour, yeast and water. Unlike the baking process, the steaming process leads to bread with a soft, moist crumb and a thin, smooth, white skin rather than the brown crust of traditional western baked bread. Due to absence of the Maillard reaction during the steaming process, CSB contains less chemoprotective compounds such as pronyl lysine compared with the baked bread, but simultaneously less toxic acrylamide and furan are generated (Zhu, 2014). Meanwhile, the relatively low steaming temperature during production better preserved the protein quality of bread ingredients than baked bread (Gotthold and Kennedy, 1964). Tsen et al. (1977) also suggested that the steaming process ensures higher availability of lysine which is the first limiting amino acid in bread and protein efficiency ratio compared with the conventional baking process. Therefore, steaming is recommended to be superior to baking in preserving protein quality of bread ingredients. This is tremendously important for the national nutrition due to the staple role of bread.

The urbanization in China greatly demands the industrialization of CSB. Freezing technology is commonly being employed for the preservation of food commodities and the bakery industry is a typical example of being exploited by freezing technology in the western countries. Meanwhile, CSB has a relatively shorter shelf-life and higher propensity to staling due to its higher moisture content as compared with baked bread. This also makes frozen dough more appealing for the industrialization of CSB (Huang et al., 2011). Despite many advantages from frozen dough, the dough gradually deteriorates during frozen storage and leads to poor loaf volume and strong alteration in textural properties of bread. The deterioration of frozen dough is still a field of active research although many alternative ways are proposed to improve its quality. Loss of yeast viability and rupture of the gluten network in frozen dough were widely studied and generally believed to be the predominant factors (Autio and Sinda, 1992). Current literature is focused on dough deterioration upon frozen storage, however, to

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the best of our knowledge, the formation of permanent structure of the gluten network and starch in the final products made from frozen dough has never been investigated. During heating of dough, the polymerization of both glutenin and gliadin involves the formation of disulfide (SS) bonds through oxidation of sulfhydryl (SH) groups and was also accompanied by starch gelatinization. The formation of a permanent gluten structure as well as the starch properties is important in establishing the structure and quality of the final products (Delcour et al., 2012).

Against this background, the objective of this study was to investigate the structural behavior of gluten and starch during the steaming process of frozen dough to fill the knowledge gap between dough deterioration and its final structure of steamed bread. Moreover, the firmness of steamed bread related to the final structure of gluten, starch and water content were also established to elucidate the relative importance of these properties to the bread texture.

2. Materials and methods

2.1. Materials

Commercial steamed bread flour (10% protein, 74% carbohydrate, 13% moisture) and active dry yeast (Angel brand, Hubei, China) were purchased from a local supermarket. Deionized water was used throughout the experiment. All the chemicals were of analytical grade unless otherwise specified.

2.2. Frozen dough preparation and steaming procedure

Chinese steamed bread was prepared according to GB/T 17320-1998 (China State Bureau of Technical Supervision, 1998). 450 g flour, 5 g yeast and 245 g water were mixed and kneaded in a mixer at 4 °C to minimize the activity of yeast. The dough was divided into 80 g pieces, molded, placed into snap lock polyethylene bags and followed by freezing at −18 °C. After fixed days of frozen storage, a batch of dough was freeze-dried and the other batch of dough was fermented at 30 ± 2 °C under 80 ± 5% relative humidity until the optimum height. The fermented dough was steamed in the boiling water for 20 min. After steaming, the bread was cooled for exactly 2 h to room temperature and packed into plastic bags or was freeze-dried for further analysis.

2.3. Determination of protein extractability in SDS solutions

SE-HPLC was performed on an LC system (Shimadzu, Kyoto, Japan). The freeze-dried samples (1 mg) were extracted with 1 mL of a 0.05 M sodium phosphate buffer (pH 6.8) containing 2.0% sodium dodecylsulphate (SDS) for 60 min at room temperature. After centrifugation at 10,000 g for 5 min, 20 μL of the supernatant was loaded on a Shodex Protein KW-804 column (Showa, Kyoto, Japan). The elution solvent was 0.05 M sodium phosphate buffer (pH 6.8) containing 0.2% SDS. The flow rate was 0.7 mL/min. The thermostat was set at 30 °C and the elution was detected at 214 nm. All extractions were performed at least in triplicate. For the elution profiles of SDS total extractable proteins (SDSEPs) of steamed bread, they were divided into two fractions using the lowest extinction value between the two peaks as the cutoff point. The higher molecular weight proteins referred to SDS extractable glutenin (SDSglut) eluted first, the lower molecular weight proteins corresponding to SDS extractable gliadin (SDSglia) thereafter. SDSEP, SDSglut and SDSglia levels were calculated from the corresponding peak areas and expressed as percentage of the total peak area of flour proteins extracted with the SDS buffer in the presence of 1.0% dithiothreitol (DTT) (Lagrain et al., 2005).

2.4. Differential scanning calorimetry (DSC) measurement

Differential scanning calorimetry (DSC) measurement was conducted using a SIINT instrument (X-DSC 7000 model, Japan) according to Keeratipibul et al. (2010). The freeze-dried steamed bread samples (4–5 mg) were accurately weighed in triplicate in aluminum pans. Deionized water was added in a ratio of 1:3 (w/w, sample dry basis:water). The pans were hermetically sealed and scanned from 0 to 120 °C at 5 °C/min (together with an empty reference pan). Before analysis, the system was calibrated with indium. The enthalpy corresponding to the melting of amylopectin crystals (ΔH) was evaluated from the thermograms by TA Rheology System Software Muse, version 1.6 (SIINT, Japan, 2012). Enthalpies were expressed in J/g of solids.

2.5. Firmness of steamed bread

Firmness of steamed bread made from dough at different times of frozen storage was analyzed by TA.XT2i (Stable Micro Systems, Ltd., Godalming, UK) using a 40 mm cylindrical acrylic probe. The bread slices (25 mm thick) were compressed at a speed of 1.7 mm/s to a total distance of 10 mm (40% strain) and withdrawn at the same speed. The firmness of bread crumb was recorded as the force at 25% strain and performed at least in triplicate.

2.6. Water content of steamed bread

The water contents of the steamed bread samples were determined using Approved Methods 44-15A (AACC International, 2000). Water content analyses were carried out at least in triplicate.

2.7. Weight loss measurement of frozen dough

To weigh the dough pieces, dough samples were removed from the polyethylene bag, transferred to the ice box and weighed; the process took less than 2 min to avoid the thaw. The weight loss was expressed as the difference between the initial value and the final weight (Phimolsiripol et al., 2011).

2.8. Statistical analysis

All data were expressed as mean ± standard deviation (SD) of at least three replicates. Data were analyzed using one-way analysis of variance (ANOVA) and means were compared by Fisher's least significant differences (LSD) test using DPS package (version 8.0 for Windows, Hangzhou). The probability value of $P < 0.05$ was considered significant. Correlation and regression studies were carried out with the SPSS package (version 13.0 for Windows, SPSS Inc., Chicago, IL).

3. Results and discussion

3.1. Effect of frozen storage on the gluten polymerization behavior in dough and steamed bread

The extractability of proteins by SDS solutions gives a good indication of the degree of crosslinking (Hayta and Schofield, 2004). During the frozen storage, the SDSEP in dough samples increased from 64.76% to 75.18% and SDSglut increased from 16.56% to 25.29%. However, SDSglia hovered at a level of 44% throughout the frozen storage period (Fig. 1a). For dough samples, the unextractable proteins in SDS solution were termed as glutenin macropolymer (GMP) with M_w over 10 million (Graveland et al., 1985). Thus, the increase in SDSEP and SDSglut levels suggested that the depolymerization of GMP had generated smaller glutenin proteins.

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