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Fermentation time and fiber effects on recrystallization of starch components and staling of bread from frozen part-baked bread

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ABSTRACT

Staling of white wheat bread produced from frozen part-baked bread (PBB) of different fermentation times (90–120–420 min) and fiber contents (6% wheat bran and 6% wheat bran +2% inulin) was studied. Volume, texture, crumb and crust water content, water activity and crumb thermal properties (including T'_m and T'_g) were measured after thawing and final baking. The results confirmed that typical freezing temperatures may not ensure the glassy state of the unfrozen phase of PBB, which may accelerate staling of final breads. The evolution of starch retrogradation, quantified by DSC, and of the crust and crumb water contents were analysed and related to the aging of bread. Firmness and cohesiveness values were used to quantify the extent of staling. Avrami equation was fitted to staling data with R^2 coefficients above 0.9 in all cases. Bread characteristics and staling kinetics were significantly affected by fermentation time and fiber, particularly inulin. Inulin promoted amylopectin recrystallization and delayed the water movement from crumb to crust during staling. The combined effects of recrystallization and water loss in the starch fraction explained firming and cohesiveness loss kinetics.

1. Introduction

The use of partial-baking technology in production of white bread from frozen part-baked bread (PBB) continues to increase (Hamdami et al., 2006). This technology has focused mainly on white wheat bread production, and the effects of fiber and the use of wholemeal flour on staling after final baking are poorly understood. From a sensory perspective staling involves the softening of the crust and the hardening of the crumb (Baik and Chinachoti, 2000). Crust softening is a consequence of migration of water from the crumb to the crust, driven by the higher water activity of the crumb (Eliasson and Larsson, 1993). Factors affecting crumb staling have been extensively investigated (Zobel and Kulp, 1996; Chinachoti and Vodovotz, 2001) and it can be largely accounted for recrystallization of amylopectin and dehydration. Most staling models used amylopectin crystallization as the primary cause for crumb firming (Zobel and Kulp, 1996). Crystallization of amylopectin entraps hydration water in crystallites and leads to redistribution of water from gluten to amylopectin which also decreases the elasticity of the gluten network (Gray and BeMiller, 2003). Consequently, an increase in amylopectin retrogradation is expected to cause increased bread firmness during storage. However, some studies have shown that both properties are not always directly related (Purhagen et al., 2011a). Some additives, such as heat-treated barley flour and waxy barley starch, decreased bread firmness even though they favoured amylopectin retrogradation (Purhagen et al., 2011a). The increase in bread water content and in water retention retarded bread staling (Purhagen et al., 2011a). Dietary fibers, such as wheat bran, have been shown to increase water absorption of dough and the initial water content of bread and to have an enhancing effect on staling parameters, e.g., firmness (Gómez et al., 2003; Wang et al., 2002).

The detrimental effect of the insoluble (oat fiber)-soluble (inulin) fiber blend on fresh and staled part-baked bread firmness has been reported (Rosell and Santos, 2010) although the origin of it was unclear.

Abbreviations: BB, wheat bran added bread; DSC, Differential scanning calorimetry; FW, frozen water; GLM, General Linear Model; IB, inulin added bread; PBB, part-baked bread; LF, Long Fermentation time; MF, Medium Fermentation time; SF, Short Fermentation time; T'_g, temperature of glass transition of the maximally freeze-concentrated state; T'_m, ice melting temperature of the maximally freeze-concentrated state.

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Fermentation time has been demonstrated to affect the initial firmness of bread and the firming rate of crumb of white and whole wheat breads (Gomez et al., 2008). However, only if fermentation time was insufficient, significant differences in crumb texture were observed (Gomez et al., 2008).

A previous study using multiple linear regression allowed us to correlate crumb hardening in a baguette-type bread with starch recrystallization and dehydration (Ronda et al. 2011). The effect of fiber on retrogradation kinetics of wheat flour blends baked in DSC pans was studied by Santos et al. (2008). However, studies of the effect of fiber and fermentation time on staling of breads from frozen PBB and its relationship with retrogradation and dehydration through numerical correlations has not been carried out. Processing parameters and method of bread making influenced bread staling (Purhagen et al., 2011b, 2011c) and differences between laboratory and industrial baking processes were detected (Purhagen et al., 2011a). Industrially baked breads were chosen for the present study. Our objective was to investigate effects of fermentation conditions and soluble and insoluble fiber on the initial quality and shelf life of breads industrially produced from frozen PBB. Avrami non-linear regression equation was fitted to amylopectin recrystallization kinetics. This exponential equation was also chosen as a useful mathematical model to properly quantify bread staling parameters. The combined effects of starch recrystallization and water loss on crumb firming and cohesiveness loss kinetics was also studied.

2. Materials and methods

2.1. Materials

The wheat flour used in the study had the following characteristics (ICC, 1996): Alveographic parameters (ICC 107/1): 82 mm, 76 mm and 211 × 10^{-4} J for tenacity (P) extensibility (L) and deformation energy (W) respectively. The farinographic parameters (ICC 115/1) were: 57.4%, 2.2 min, 8.2 min and 42 BU for water absorption, dough development time, stability and decay in 10 min respectively. Wheat bran (45% (w/w) insoluble fiber) was purchased from Harinera La Meta (Spain). The particle size distribution of bran (supplier data) was: 34.2% > 1400 μm, 1400 μm > 32.5% > 630 μm, 630 μm > 24.1% > 350 μm, 9.2% < 350 μm. Inulin (Fibruline-Instant, 90% purity) was purchased from Cosucra (Belgium). The improver, a mixture of ascorbic acid, diacetyl tartaric ester of monoglyceride, α-amylase and hemicellulase, was supplied by Leag-Eurogerm (Barcelona, Spain).

2.2. Bread production

All the breads included in the study were designed from preliminary tests and market studies that included consumer sensory evaluations. Longer fermentation times led to breads of better flavour and texture, particularly LF bread, that were very appreciated by consumers. Fiber-added breads were targeted to consumers who valued healthier products. These breads got a good sensory evaluation increasing significantly the fiber content with respect to the control bread. Then, all the breads included in this study were of commercial quality.

The breads used were produced industrially using a *Sancassiano Continuous Force* (Alba, Italy) kneading system and a Mecatherm production line (Barembach, France) in a direct process. The ingredients were pre-mixed for 3 min and the homogeneous mix was delivered to the kneading chamber where was mixed for 10 min. All formula included, on a 100 g wheat flour basis: water (58–62%), yeast (2% w/w), salt (1.8%. w/w), and bread improver (0.5% w/w). Doughs were divided into Short Fermentation dough (SF) with a standard fermentation time of 90 min, Medium Fermentation dough (MF) with a first fermentation step of 30 min followed by the standard fermentation as for SF, and Long Fermentation dough (LF) using a fermentation step of 300 min to 30% of the dough. This prefermented fraction was mixed by kneading to MF dough to obtain 100% LF. Breads with added fiber contained either insoluble fiber (6% (w/w) wheat bran in flour) (BB) or both insoluble and soluble fiber (2%, w/w, inulin with 6% (w/w) wheat bran in flour) (IB). BB and IB doughs used 90 min fermentation as described for SF. The fermentation took place at 28 °C and 75% relative humidity.

The dough hydrations used in the fiber-added formulations were 3% and 4% above that of the control bread, 58%, for BB and IB respectively. The flour/fiber-to-water ratios in doughs were adjusted by a professional baker so as to obtain similar stiffness as that of the control dough (SF). The control dough hydration was obtained form farinographic test.

The final total dietary fiber contents (AOAC 1998 method 991.43) in BB and IB breads were 7.8 ± 0.6% and 10.2 ± 0.6%, respectively, while in the control bread was 5.0 ± 0.6%. The final inulin content (AOAC 1998 method 999.03) in IB bread was 1.7 ± 0.3%.

All breads were part-baked at 185 °C for 11 min and cooled at room temperature during 30 min until getting 40–45 °C in the bread core. After cooling, the part-baked breads, of a mean weight of 150 g, were deep-frozen in a forced convection freezer at −38 °C during 45 min, until getting −12 °C in the core of the loaf (approximate heat transfer coefficient 25 W/m^2 K). Then, part-baked breads were packed in individual plastic bags and a cardboard box, and stored at (−18 ± 2) °C for 7 days. These part-baked breads, before analysis, were thawed at room temperature (45 min) and, after unwrapping, baking was completed at 190 °C in a Salva convection oven (Lezo, Spain) for 18 min. Baked breads were cooled at room temperature for 1 h before analyses. The breads designated to the staling study were packaged in hermetically sealed polypropylene bags and stored at (4 ± 2) °C for 0, 1, 2, 4, 6 and 9 days.

2.3. Thermal analysis

A Metller Toledo-DSC 822e (Schwerzenbch, Switzerland) equipped with a ceramic sensor (FSR5) of high sensitivity, liquid nitrogen cooling system and nitrogen purge gas was used. DSC used 20–25 mg of bread crumb samples taken from the centre of the bread loaf and aluminium pans of 40 μL. The glass transition (T'_g) of maximally freeze-concentrated solutes and the onset of ice melting (T'_m) temperatures were obtained as reported by Roos and Karel (1991). The ice melting temperature of the maximally freeze-concentrated system was measured after annealing of samples for 15 min at a temperature slightly below T'_m. Samples were cooled at −20 °C/min from 25 °C to −80 °C, heated again until the annealing temperature at 10 °C/min and cooled to −100 °C at −20 °C/min. The final scan was at 5 °C/min to 25 °C. The annealing temperatures were −21 °C for SF, MF and LF and −23 °C for BB and IB. The T'_m values are the average of at least three determinations. The annealing temperatures were chosen for each system at 2 °C below the onset ice melting temperature, T'_m, found in preliminary tests. Starch retrogradation was analyzed from DSC endotherms obtained for crumb samples during temperature scanning from 0 °C to 105 °C at a heating rate of 5 °C/min. Each measurement was performed at least in duplicate. The melting enthalpy was expressed in J/g of solids.

2.4. Water content

Water content was determined for crumb and crust in duplicate following the standard method 44-15A (AACC, 2000). The crust