Journal of Food Engineering 204 (2017) 1–7

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Ultrasonic investigation of the effects of composition on the volume fraction of bubbles and changes in their relative sizes in non-yeasted gluten-starch blend doughs

Filiz Koksel [a], [*], Anatoliy Strybulevych [b], John H. Page [b], Martin G. Scanlon [a]

[a] Department of Food Science, University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2N2
[b] Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2N2

ARTICLE INFO

Article history:
Received 24 May 2016
Received in revised form
23 January 2017
Accepted 28 January 2017
Available online 31 January 2017

Keywords:
Gluten
Starch
Water
Dough
Ultrasound
Bubble size distribution

ABSTRACT

Interactions between water, gluten and starch during dough mixing alter the aeration properties of dough. Effects of composition on dough gas volume fraction and relative changes in bubble sizes of non-yeasted gluten-starch (G-S) blend doughs were investigated using density measurements and an ultrasonic transmission technique, respectively. At fixed water content, greater gluten content increased the air volume fraction, while frequency-dependent ultrasonic attenuation coefficient and phase velocity measurements indicated that the bubble sizes in the G-S doughs were larger. The latter outcome may be due to mixing to optimal conditions such that shorter mixing times for doughs of high gluten content lessened the number of bubble subdivision events during mixing. The effect of increased water content on the attenuation coefficient implied a decrease in mean bubble radius as elucidated using an ultrasonic model. Time evolutions of attenuation coefficient and phase velocity for G-S blend doughs had a similar trend to those of non-yeasted wheat flour doughs. However, the shifts in the frequency of the peaks observed in the ultrasonic parameters were noticeably slower for G-S blend doughs, implying that G-S blend doughs were more stable against disproportionation.

1. Introduction

There is a significant relationship between dough aeration during mixing and the cellular structure of the baked bread (Campbell et al., 2001, 1998). It has been shown that dough aeration is influenced by mixer type (Peighambardoust et al., 2010; Whitworth and Alava, 1999), mixing headspace pressure (Chin et al., 2004; Elmehdi et al., 2004), mixing time (Campbell et al., 1998; Mehta et al., 2009), water content (Chin et al., 2005; Peighambardoust et al., 2010) and various other dough ingredients (Chin et al., 2005; Mehta et al., 2009). Resolving how dough properties are affected by changes in ingredients and mixing process parameters is not a trivial task (Koksel and Scanlon, 2012), so that understanding the mechanisms governing the changes in dough aeration is a longstanding research challenge (Baker and Mize, 1941).

Working with model gluten-starch (G-S) blend doughs enables the role of gluten and starch in dough systems to be probed in a simple way (Uthayakumaran and Lukow, 2003; Watanabe et al., 2002; Yang et al., 2011). The complexity of interactions of protein and starch with other constituents (*e.g.*, pentosans, damaged starch, endogenous lipids and enzymes) is minimized (Petrofsky and Hoseney, 1995; Uthayakumaran and Lukow, 2003), while the use of gluten from one source eliminates variations that arise from proteins of different characteristics. Moreover, non-yeasted G-S blend doughs are relatively stable systems that do not allow bubbles to cream out so that changes in the concentration and sizes of bubbles can be studied as a function of time. Despite the simplifications afforded by G-S blends, it is still experimentally very challenging to study bubbles and their evolution since all doughs lack optical transparency, bubbles change rapidly and they are very fragile (Bellido et al., 2006; Shimiya and Nakamura, 1997; Strybulevych et al., 2012).

Investigations of bubble size distributions (BSDs) in dough have been conducted with several methods, including light microscopy (Carlson and Bohlin, 1978), conventional bench-top X-ray microtomography (Bellido et al., 2006), synchrotron X-ray microtomography (Koksel et al., 2016; Turbin-Orger et al., 2012), magnetic resonance imaging (De Guio et al., 2009), and confocal

---

[*] Corresponding author.

http://dx.doi.org/10.1016/j.jfoodeng.2017.01.027
0260-8774/

laser scanning microscopy (Upadhyay et al., 2012). Low-intensity ultrasound has also been used to characterize dough aeration (Elmehdi et al., 2004, 2005), because its rapid and non-destructive nature makes it well suited for studying these optically opaque systems (Koksel et al., 2014; Létang et al., 2001; Ross et al., 2004; Scanlon et al., 2008; Strybulevych et al., 2012). Of particular interest in determination of bubble sizes in dough, a broad band of appropriate frequencies can be used to ascertain bubble sizes from the measured ultrasonic parameters, *i.e.*, from the phase velocity and attenuation coefficient (Leroy et al., 2008; Scanlon and Page, 2015). Precise ultrasonic determinations of the bubble size distribution (BSD) in bread dough is still being established (Leroy et al., 2008; Scanlon and Page, 2015), but changes in the distribution are readily accessible from changes in the bubbles' acoustic signature (Koksel et al., 2014; Strybulevych et al., 2012).

To better understand how the various components of the dough matrix interact to alter dough aeration properties, the first objective of this study was to use the bubbles' acoustic signature to investigate how changes in the volume fraction of starch granules and the hydration of the gluten affect the amount of gas occluded into the dough during mixing. The second objective was to investigate the rate of relative change in the BSD in these different "dough" systems based on time-dependent changes in the acoustic signature.

2. Materials and methods

2.1. Sample preparation

Dough ingredient specifications (Koksel and Scanlon, 2012) and sample preparation for ultrasonic measurements (Koksel et al., 2014) are in accordance with previous descriptions. Gluten-starch (G-S) blend doughs of varying composition were prepared by addition of saline solution (3.2% w/w) at 90, 95 and 100% (total G-S blend weight basis). Neither yeast nor leavening agents were used in the G-S blend dough formulation. Therefore changes in bubbles will arise only from disproportionation (Ettelaie and Murray, 2014; van Vliet, 1999). G-S doughs were prepared either by varying gluten content or water content based on weights of gluten and starch, as determined on a 14% m.b. (Table 1). For doughs with varying gluten content, water content was kept constant at 90% (total blend weight basis).

G-S blend doughs at each formulation were prepared using a pin mixer with a 200 g mixing bowl (National MFG. Co., Lincoln, NE, USA). Each G-S blend was mixed (116 rpm) for 1 min prior to water addition and then mixed until its peak time (Table 1) as determined from the mixing curves produced by the pin mixer. Dough temperature at the end of mixing (23 ± 0.5 °C) was controlled by a water circulation unit (Haake C, Berlin, Germany) connected to the mixing bowl.

2.2. Experimental methods

The experimental set-up for testing of doughs was comprised of an ultrasonic pulse generator/receiver (Panametrics, Olympus NDT Waltham, MA, USA), a pair of transducers (central frequency: 2.25 MHz, Olympus NDT Waltham, MA, USA), and a digital oscilloscope (Tektronix Digital Oscilloscope, TDS5032B, Tektronix Inc., Beaverton, OR, USA). A dough subsample was placed between a pair of acrylic delay lines situated between the generating and receiving transducers. The ultrasonic pulse that left the generating transducer was transmitted through the first delay line, the dough subsample, the second delay line and then it was detected by the receiving transducer. To create the reference signal, a signal was acquired with the delay lines in direct contact (Koksel et al., 2014).

The first ultrasonic signal was recorded 15 min after the end of mixing, and then every 15 min for 2 h so that changes in the signal could be followed as a function of time. All ultrasonic experiments were performed inside a temperature (23 ± 0.1 °C) and humidity (85 ± 1.0% relative humidity) controlled cabinet (Caron Products and Services Inc., Model: Caron 6010, Marietta, OH, USA).

The ultrasonic attenuation coefficient (α) and phase velocity (v) depend on the magnitudes and phases of the Fourier transforms, respectively, and were calculated according to Koksel et al. (2014). The acquired signals were corrected in order to account for the acoustic impedance mismatch at the dough-acrylic delay line interfaces (Fan et al., 2013).

Dough density (ρ) measurements were performed in a specific gravity bottle by water displacement (Koksel and Scanlon, 2012). Dough matrix density (ρ_M) was estimated by applying the rule of mixtures, considering the density and mass of gluten, starch, salt (NaCl) and water. Using a pycnometer, the densities of gluten and starch were measured as 1285 kg/m^3 and 1469 kg/m^3, respectively (Koksel and Scanlon, 2012). Air volume fraction (Φ) was calculated from dough density and matrix density [$\Phi = (1 - \rho/\rho_M) \times 100$ when expressed as a percentage].

3. Results and discussion

3.1. Effects of gluten, starch and water on dough density

The effects of composition on dough density, dough matrix density and air volume fraction are shown in Table 2. At a given water content, dough density decreased as gluten content increased, which resulted in a greater air volume fraction since the calculated dough matrix density decreased only slowly with increasing gluten. This result accords with the results of Koksel and Scanlon (2012), who reported that when doughs are mixed for a fixed period of time, dough density decreases as gluten content increases. Thus, even though longer mixing times promote air entrainment in dough (Mehta et al., 2009), these results indicate that gluten content has a pronounced effect on air entrainment since optimal development for the higher gluten content samples required shorter mix times (Table 1).

An increase in water content did not substantially affect dough density (Table 2). It has previously been reported that lowering water content (from optimum farinograph absorption to 5% below optimum) depresses the density of wheat flour doughs (Peighambardoust et al., 2010) and G-S blend doughs mixed for a fixed time (Koksel and Scanlon, 2012). The difference between the results of our study and those reported by Peighambardoust et al. (2010) and by Koksel and Scanlon (2012) can be partially attributed to the high water contents in our G-S blend doughs and the mixing protocol used for the G-S blend doughs in our study, which were mixed to their peak time. If a fixed mixing time (longer than the peak time) had been chosen, the enhanced air entrainment effect of long mixing time (Campbell et al., 1998; Mehta et al., 2009) would be expected to dominate over the hydration effects occurring at shorter mixing times (Koksel and Scanlon, 2012), so that void fractions would be larger for drier G-S blend doughs with lower peak times. Since each G-S blend dough formulation is mixed until its peak time, continuous air occlusion during overmixing was not an issue for the dough samples in this study. The cohesion of starch granules and protein in G-S blend doughs during mixing differs from that in wheat flour doughs (Koksel and Scanlon, 2012). Accordingly, there is a significant interaction of water content and mixing time for this atypical dough system that influences the aeration of G-S blend doughs.