Food Research International 64 (2014) 587–597

Contents lists available at ScienceDirect

Food Research International

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

Flour quality and disproportionation of bubbles in bread doughs

Sumana Chakrabarti-Bell [a,b], Shuo Wang [a,b,c,*], Kadambot H.M. Siddique [d]

[a] CSIRO, Animal, Food and Health Sciences, 26 Dick Perry Avenue, Kensington, WA 6151, Australia
[b] CSIRO Food Futures National Research Flagship, GPO Box 1600, Canberra, ACT 2601, Australia
[c] School of Earth and Environment, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
[d] The UWA Institute of Agriculture, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

ARTICLE INFO

Article history:
Received 2 May 2014
Accepted 20 July 2014
Available online 1 August 2014

Keywords:
Bubbles in doughs
Partial coalescence
Dough rheology
X-ray microtomography
Ostwald ripening
Scientific visualization

ABSTRACT

The bread making process transforms wheat flour doughs into highly porous breads. Bread has been shown (Wang, Austin and Bell, 2011) to be a single, open cell that is massively interconnected giving it a maze-like structure that encompasses the entire volume. The solid strands are also porous and contain closed cells. How the bubbles in dough mix partition into these open and closed cells in bread is not known. This study was undertaken to track changes in bubbles in doughs using 3-D X-ray microtomography techniques as doughs proofed and were baked. The mechanical properties of doughs were measured to establish how dough rheology impacted bubble growth. The doughs were made with 'medium strong' Canadian flour (CWRS) and 'weak' Australian flours (Wylk). Both doughs had similar protein amounts and strain-hardening characteristics; however the CWRS dough was more elastic. The scans identified formation of clusters of partially-coalesced bubbles from which one cluster grew to form a massively interconnected, single, closed cell in doughs as doughs proofed. Microscopy studies confirmed that the open cell in breads was made of partially-coalesced bubbles. Compared to the dough made with the Australian flours, the dough made from Canadian flour had a thicker dough layer separating bubbles, smaller size bubbles and a slower rate of formation of the continuous structure. This study highlights the critical role of dough elasticity and the disproportionation phenomena of bubble growth in controlling the quality of cell structures in dough and baked products.

1. Introduction

Conventionally, flours with high levels of gluten protein (12–14% by flour weight) are used to make breads. The cereal industry measures the amount of protein in flour and dough strength to characterize and thereby, select wheat for baking (Hoseney, 1994). Although the amount of protein influences the selection of wheat for baking, studies (Dobraszczyk & Morgenstern, 2003) have shown that protein content correlated only poorly with bake volumes, which implies that protein amount is not the sole driver for baking functionality of flours. To date, short of baking, there are no assured methods to select flours for baking. Generally, high protein North American (NA) wheat is known to bake larger loaves and is preferred for baking (Dobraszczyk, 1997; Halton & Scott Blair, 1936). The reasons for superior baking qualities of NA wheat are not understood. In the grain industry, flours are classified as either strong or weak for baking performances. Breads made of weak flours tend to lack proofing tolerance, produce smaller loaves which can be crooked in shape and have sub-standard bread texture.

Breads are highly porous materials. Air bubbles are trapped in doughs during mixing. These bubbles act as nucleation sites for leavening gases to collect and dough to rise (Baker & Mize, 1940; Chin & Campbell, 2005; Gan et al., 1990). In the oven, the bubbles expand further, starch gelatinizes and moisture evaporates leading to the formation of crusts and crumbs of breads. Ultimately, gas bubbles fracture which stabilizes the internal pressure in breads with that of the atmosphere. This explains why breads do not collapse when taken out of the oven. The sizes of loaves together with quality of crumbs (hard versus soft, crumbly versus pliable, springy versus plastic, etc.) define bread quality. Wang, Austin, and Bell (2011) have showed that breads made with 'strong' flours had soft, pliable crumbs while those from 'weak' flours had firmer, brittle crumbs.

How dough rheology affects expansion and coalescence of bubbles in doughs has been the subject of much research. The wheat flour doughs have the unique ability to stretch. It is thought that the more dough could stretch without rupturing, the greater the likelihood of bubbles expanding more and loaves to become large (Gan et al., 1990). However, as bubbles expand, the likelihood of coalescence between bubbles increases, compromising of crumb quality and loaf volume. It has been suggested that bubble growth is likely controlled by Ostwald ripening or the process of disproportionation

---

* Corresponding author at: 26 Dick Perry Avenue, Kensington, Perth, Western Australia, 6151, Australia. Tel.: +61 8 6436 8749.
E-mail address: shuo@shuo-wang.com (S. Wang).

http://dx.doi.org/10.1016/j.foodres.2014.07.025
0963-9969/© 2014 Elsevier Ltd. All rights reserved.

(Mills, Wilde, Salt, & Skeggs, 2003) which would mean that larger bubbles will grow at the expense of smaller bubbles.

It is known that dough strain-hardens during stretching. It has been hypothesized that by hardening up, dough would limit the growth of bubbles, reduce coalescence between bubbles and thereby increase loaf volumes (Dobraszczyk, Smewing, Albertini, Maesmans, & Schofield, 2003; Van Vliet, Janssen, Bloksma, & Walstra, 1992). However, bread doughs are elastic and large loaves are formed from high elasticity doughs (Halton & Scott Blair, 1936). The North American flours are known to mix more elastic doughs than those made obtained from Australian flours (Halton & Scott Blair, 1936; Patel & Chakrabarti-Bell, 2013). With the introduction of shear rheometers, dough elasticity has been measured at low shear strains, but no correlation with baking qualities has been observed (Stojceska & Butler, 2012).

Recent studies by Chakrabarti-Bell, Wang and Patel (2013) have shown that dough elasticity, measured from large deformation, true strain rate, compression–recovery tests, successfully differentiated between a range of chapatti doughs (a type of Indian flatbread) for their gas holding abilities. By visualizing bubble structures using microtomography techniques, the authors reported that in chapatti doughs of atta flour (wheat grown in India, preferred for making chapattis), the solid layers in-between air bubbles were thicker, presumably due to greater elasticity of dough which meant doughs regained thickness better when rolled. The atta doughs lost fewer bubbles, the puffed layers in baked products were more porous and thus, softer in texture. To date, there is no information how dough elasticity affects the formation of crumbs in breads.

1.1. Visualization of bubbles

The importance of crumb quality on bread quality is well established in cereal sciences (Cauvain, 1999). Attempts to visualize bubbles in doughs continue to be researched. MRI was used by Rouillé, Bonny, Della Valle, Devaux, and Renou (2005) to see if bubbles were encased by a liquid film. No conclusive evidence was found. Using 3-D microtomography, Bellido, Scanlon, Page, and Hallgrimsson (2006) reported that dough contained numerous bubbles, mostly invisible to the naked eye. Dough proofing was studied by Babin et al. (2006) using 3-D high speed synchrotron tomography. These authors reported that bubbles coalesced and became 'non-spherical' during proofing and that the thickness of dough layers around bubbles first decreased and then increased. Visualizing the voids in breads using 3-D microtomography techniques, Wang et al. (2011) reported that bread is a single, open cell that is massively interconnected and has a maze-like structure that encompasses the entire volume of a loaf. The solid strands are also porous and contain closed cells. The differences in bread porosity and the distribution of open and closed cells largely defined firmness and texture of loaves. The 'weaker' flours produced firmer and cakey texture breads. How the bubbles in doughs separate into open and closed cells in breads is not understood at this time and that is the aim of this study.

The study is designed to analyze the interactions between flour, dough elasticity and growth of bubbles as doughs are mixed, proofed and baked. A Canadian and an Australian flour of similar protein amounts were selected. The amount of water was adjusted between doughs such that doughs had similar strain-hardening characteristics but differed in elastic responses. To incorporate kneading effects in preparing samples for testing, dough samples were stretched and released under controlled conditions of rate of stretch using an Instron. Portions were cut from the stretched strands of doughs and either frozen immediately to represent dough at zero time of proofing or proofed for various times and then frozen. Methods were developed to scan frozen doughs using a 3-D microtomography technique. The breads corresponding to various periods of proofing were baked and scanned. The study has given insights into the mechanisms of bubble growth and how flours affect quality of breads. Results are discussed below.

2. Materials and methods

2.1. Materials

The Australian flour was Wylkatchem (Wylk), a single variety wheat flour (Australian Premium White, considered 'weak' for baking) and the Canadian flour was a single variety Canadian Western Red Spring (CWRS), considered 'medium strong' for baking. The optimal water absorptions for Wylk and CWRS were 59.9% and 54.9% dough moisture, respectively (measured from Farinograph mixing, forming doughs of 500BU). The extraction rate of both flours was 70%. Ash content was not measured. Doughs were formulated to have similar rheological characteristics. The CWRS flour had 11.8% protein and 7.4% damaged starch, while Wylk had 11.7% protein and 7.0% damaged starch.

2.1.1. Mixing doughs

Optimal water doughs were mixed in 400 g batches using only flour, water and yeast. A six pin mixer (National MFG Co., Lincoln, NE) with an adjustable frequency drive (GE AF-300g11) operating at a speed of 100 rpm was used to mix the dough. Doughs were mixed optimally as given by mixer power curves with CWRS requiring 8.3 and Wylk 5.7 Whr/kg respectively. Portions were cut and frozen for CT scanning. Unleavened doughs were mixed only for dough rheology testing.

2.1.2. Samples used for visualization

2.1.2.1. Doughs. During kneading, dough is exposed to varying levels of stretch and stretch rates. To incorporate kneading effects, dough strands were stretched in an Instron 8872 servo-hydraulic material tester at true strain rates of 0.05, 0.5 and 5/s to strains of 1 and then released from stretch. Thus, dough strands were stretched and had elastic recoveries. A portion was cut from the recovered strands, proofed for 0, 10, 20 or 30 min and then frozen for later visualization. Thus, for each rate, samples proofed for different times had an identical mechanical deformation. The above procedure was repeated for both flours giving two sets of dough samples with identical histories for sample preparation. These samples were not baked.

2.1.2.2. Breads. A fresh mix of leavened dough was divided into 5 g samples and shaped into a cylinder using a molder. Samples were placed in a proofer and proofed for up to 50 min at 10 min intervals. After proofing, samples were baked (Moffat Turbofan E32M) at 180 °C for 10 min. Baked bread samples were cooled. Samples were weighed on a digital scale and lengths and diameters recorded to calculate specific volume (SV, inverse of density).

2.2. Methods

2.2.1. Dough rheology testing and characterization

True strain rate, uniaxial, compression tests were performed using dough cylinders and an Instron 8872 servo-hydraulic material tester. An actuator arm controlling the location and movement of the top platen was programmed using Instron's WaveMatrix Dynamic Testing Software (www.instron.com.au). Test methods similar to those used in this work have been previously reported (Chakrabarti-Bell, Bergström, Lindskog, & Sridhar, 2010; Patel & Chakrabarti-Bell, 2013).

Samples were shaped using a mold to form cylinders (22 mm high, 22 mm diameter). Samples were placed on lubricated platens and compressed to a strain of 0.8 at rates of 0.05, 0.5, and 5/s. Displacement and force data were automatically recorded and converted to stress and strain data.

$$\text{True Strain} = -\ln(1-\Delta h/h_0) \tag{1}$$

$$\text{True Stress} = F/A = F/\left(\pi r^2 h_0/\Delta h\right) \tag{2}$$