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Bubbles in chapatti doughs

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ABSTRACT

Traditionally, chapattis are flatbreads made from atta (wholemeal Indian wheat flour). Non-atta chapattis have not been popular due to substandard product quality. To investigate what makes atta special for making chapattis, products were made using atta, Australian wholemeal wheat flour, gluten-free lupin flour, and a blend of lupin and wheat flours. Doughs were characterised by measuring strain-hardening and elastic recovery in compression and also bubble structures *via* 3-D X-ray micro-tomography. A method was developed to identify and separate bran, which appears as bubbles, in scans of doughs.

Results highlighted the following: (1) elasticity of doughs is important for stabilising bubbles during rolling and baking, (2) atta doughs are low in strain-hardening but high in elasticity and retain bubbles the best after baking, and (3) lupins can be used to increase elasticity of Australian wheat flour doughs and to make gluten-free chapattis.

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1. Introduction

Chapattis are unleavened flat breads and a staple food made in Indian homes, shops and restaurants. Atta flour is widely used to make chapattis and is obtained by grinding wheat grown in India and Pakistan. To make chapattis, atta is hand-mixed with water and salt to form dough. Small pieces (~30 to 40 g) are torn from the dough mass and sheeted using a hand roller to form thin, round, flat sheets. These sheets are first warmed on hot, flat pans until some bubbles inflate and become visible. This process slightly hardens the surface in contact with the pan. The chapatti is then flipped to harden the other side, and is then placed over an open flame where the chapatti puffs like a balloon. This puffing process is fast, else the pieces burn.

The hardening of surfaces occurs from gelatinisation of starch, while puffing occurs from the generation and rapid accumulation of steam in the sheet during heating. Separation of the crust layers begins at several points and as baking continues, these areas enlarge and ultimately coalesce to produce one large bubble (the puff) delineated by intact top and bottom layers. Usually the top layer is thinner than the bottom layer. The quality of chapattis is high when they puff fully and remain soft and pliable during storage.

Substituting atta with wheat grown outside the Indian subcontinent has been met with limited success due to issues in rolling doughs into sheets (the pre-baked chapattis) and with consumer dissatisfaction with product texture. What makes atta so suitable for chapattis? Research has highlighted the importance of gluten composition, milling conditions and dough sheetability. Analyses of wheat varieties grown in India have shown that the best varieties have a unique composition of gluten proteins containing similar amounts of gliadin, glutenin and residual proteins; the latter are proteins that are un-extractable from gluten in presence of acetic acid (Ram and Nigam, 1981; Srivastava et al., 2002). Milling is critical in that the amount of damaged starch in the flour influences puffing and the right amount helps maintain a soft, pliable product texture (Rao et al., 1989). Ghodke et al. (2009) have reported the milling conditions necessary to control the amount of damaged starch in flours, although an optimal value was not reported.

The ‘sheetability’ of chapatti doughs is important as the final thickness of the rolled sheet affects the quality of baked chapattis. Optimal thicknesses for atta doughs have been reported to be in the range 2–2.5 mm for obtaining fully puffed, soft and pliable chapattis (Rao et al., 1986). Although dough sheets of ~1 mm thickness puffed fully, their eating qualities were unacceptable. At thicknesses >2.5 mm, chapattis had under-baked qualities.

Abbreviations: CSIRO, Commonwealth Scientific and Industrial Research Organisation; micro-CT, computerised X-ray micro-tomography.

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In a study comparing a range of British wheat cultivars, Rehman et al. (2007a) showed that none of the cultivars matched the sheetability of atta as doughs were either too elastic (large shrink-back following sheeting), too 'short' or too spreadable. However, a mix of two varieties – Mercia and Galahad, showed promise (Rehman et al., 2007b).

Supplementing atta flour with flours made from various legumes increases protein and mineral content and therefore increases the nutritional content of chapattis. This is a long-desired goal in developing countries. However, the texture of the resulting chapattis has been substandard. With soy, the maximum amount for soy incorporation was found to be 24% (w/w flour) (Khan et al., 2005). The acceptability limit for inclusion of chick pea flour was around 20% (Singh et al., 1991). On the other hand, a 3% addition of guar gum to atta resulted in an improvement in both puffing and softness of chapattis (Gujral and Pathak, 2002).

Lupin, sometimes called sweet lupin, is an Australian-grown legume rich in micro-nutrients and contains high levels of protein and fibre. Lupin and lupin-wheat flour blends are used to make chapatti-like flat breads in Australia. Importantly, lupin contains no gluten. In clinical studies, lupin has been shown to reduce blood sugar and promote high levels of satiety (Lee et al., 2006, 2009). Long range structures in lupin doughs have been detected by confocal microscopy (Øiseth and Chakrabarti-Bell, 2012). Also an interaction between β-conglutins, one of the proteins in lupins, and gluten proteins has also been reported by Islam et al. (2011) in lupin breads.

These lupin doughs puff like atta chapattis although textural differences remain. However, given that lupin contains no starch and lupin doughs are not extensible, how lupins make chapattis is not easily understood.

There is little information in the literature (to the authors' knowledge) regarding dough properties necessary for puffing. However, there are numerous studies investigating the bread-making qualities of flours. Besides the obvious differences in product appearance and texture, structurally breads and chapattis are also different. Chapattis contain one large, closed bubble (the puff), while bread crumb is made up of a single, interconnected 'open bubble' comprising ~99.9% of the volume fraction of bubbles (Wang et al., 2011). Some closed bubbles are also present in the strands of solid phase in crumbs. The ratio of open bubble volume fraction to total bubble volume fraction has been shown to increase with bread softness (Wang et al., 2011). On the other hand, the pliability of breads is affected by the distribution of closed cells (Wang et al. 2011). Softness and pliability are critical textural attributes for chapattis also. Therefore, a brief review of the current understanding of dough properties, that govern bubble growth and stability in bread doughs, follows.

1.1. Strain-hardening of doughs and bubble stability

Wheat flour makes strong viscoelastic doughs, a feature considered essential for protecting air (or gas) bubbles as they are trapped inside the dough during mixing. A film of dough encases each bubble and also protects it from coalescing and/or break-up during processing and baking (Sroan et al., 2009).

Being viscoelastic, the film is able to stretch as bubbles deform (Bloksma, 1990; Sroan et al., 2009). It is thought that the more dough can stretch before rupturing, the more bubbles can grow and the larger the loaf volume. Hence the rupture strengths of doughs are measured in order to determine bread-making potentials of flours. These tests are performed using either quasi-uniaxial stretching (Brabender Extensograph) or quasi-biaxial stretching (Chopin Alveograph). Doughs exhibit a hyperelastic stress–strain function during stretching. Either a power law or an exponential curve can be fitted to the stress–strain plot (Bagley et al., 1988; van Vliet et al., 1992). The coefficients of the fitted curve can be used as measures of strain-hardening quality of doughs, thought to be important for limiting Ostwald ripening (expansion of large bubbles at the expense of smaller bubbles) and for hindering coalescence of bubbles as they grow during proofing and baking (van Vliet, 2008; van Vliet et al., 1992).

To obtain values of rupture strengths in engineering units, the Alveograph test was adapted to run in a material tester. Rupture strength and strain-hardening properties of doughs corresponding to a range of flours were measured. Results showed a positive correlation between loaf volume and failure strain and strain-hardening coefficient (Dobraszczyk et al., 2003). A value of one for strain-hardening index, obtained by fitting an exponential to the hyperelastic stress–strain curve, was proposed as a cut-off between strong and weak flours with stronger flours having values greater than one. That rupture strain is correlated to strain-hardening index (obtained from dough inflation tests) has been shown also by Chin and Campbell (2005).

An interaction between strain-hardening and the level of aeration in doughs has been reported by Chin et al. (2005). In a series of experiments, doughs were mixed under vacuum and under varying atmospheric pressures. The biaxial strain-hardening indices were found to be smaller for doughs made with weak flours, and decreased as the volume of trapped air increased during mixing (Chin et al., 2005). For example, the strain-hardening index of vacuum-mixed, strong doughs dropped from 2.1 to 1.8 when mixed to contain ~12% air. For doughs of weak flours with similar volumes of air in doughs, the index dropped from 1.8 to 1.5. The above authors also reported that comparatively more air is trapped in weak flour doughs when mixed under atmospheric pressure.

Chapatti flours are not considered to be strong, bread-making flours. Thus, low levels of biaxial strain-hardening indices could explain the puffing of chapattis resulting from rapid coalescence of expanding gas bubbles.

1.2. Elasticity of doughs and bubble stability

Besides biaxial strain-hardening, dough elasticity is also known to be important for defining the bread-making potential of flours. Note while strain-hardening indicates the resistance of dough to thinning out upon stretching, elasticity indicates the readiness of doughs to recover thickness when released from stretching. Using data obtained from a series of stretch-recovery experiments, a mechanical model was derived using springs and 'capacitors', *i.e.* the predecessor of dashpots in current concepts of polymer viscoelasticity, to describe dough's strain-hardening and elastic recoveries (Schofield and Scott Blair, 1933). Methodologies to determine dough's relaxation time and elasticity were reported by Halton and Scott Blair (1936), and then used to establish that doughs of superior bread-making qualities were more elastic and had longer relaxation times.

Applying the elasticity concept to stretching of dough layers between bubbles as they grow, it can be argued that doughs of higher elasticity would restrict coalescence of bubbles by maintaining thickness of the dough layer more effectively. Conversely, bubbles in doughs of lower elasticity would grow to coalesce earlier as the dough layer would thin out more quickly. An optimal level of elasticity is known to be a key quality parameter for chapatti doughs (see discussion on selection of wheat varieties for atta).

New techniques have been reported (Chakrabarti-Bell et al., 2010) for measuring the elasticity and strain-hardening of doughs from compression–decompression (unloading) tests performed at constant true strain rates. Alongside, distribution of bubbles in bread doughs has been determined using 3-D X-ray computed micro-tomography methods or (micro) CT scanning (Bellido et al., 2006). Combined with the development of dedicated workflows,

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