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Mechanical and microstructural changes of cheese cracker dough during baking

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ABSTRACT

Baked food snacks constitute an important market as a popular consumer product. The mechanical properties of cheese cracker dough at different stages of baking have been investigated as they can relate to the product's texture. The change in mechanical properties during baking was measured whilst the corresponding changes in microstructure were recorded using cryo-SEM at several interrupted baking conditions. The initial modulus of the dough increased with baking time due to starch melting or gelatinisation, melting of fat globules and evaporation of water. Simultaneously gas cells were found to begin forming. The data derived from the uniaxial compression, tension and shear experiments showed that the dough exhibited a rate dependent behaviour at all stages of baking with a power law index of approximately 0.2. Rheometric tests under dynamic heating conditions were also performed and it was found that the modulus decreased significantly, from 150 kPa to 10 kPa, with the initial rise in temperature. This study provides useful data for understanding the evolution of microstructure and rheology during the baking process and its impact on the texture of the final product.

1. Introduction

Several studies have focused on relating the texture evaluation of food products as measured from sensory panels to their instrumental mechanical properties (Tunick et al., 2013; Booth, Earl, & Mobini, 2003; Segnini, Dejmek, & Öste, 1999). The mechanical properties of simple food materials, such as model dough systems (Dreese, Faubion, & Hoseney, 1988a; Dreese, Faubion, & Hoseney, 1988b; Mohammed, Tarleton, Charalambides, & Williams, 2011) and cake batter structures (Chesterton, Meza, Moggridge, Sadd, & Wilson, 2011; Chesterton, de Abreu, Moggridge, Sadd, & Wilson, 2013) have been studied extensively as raw, unbaked materials. The contribution of the individual ingredients towards the final product after baking has also been studied by several authors (Baltsavias, Jurgens, & Van Vliet, 1999; Chevallier, Colonna, Della Valle, & Lourdin, 2000). In addition, various microscopy methods have been used to investigate the microstructure of cooked cake dough as a function of cooking method, i.e. conventional oven or microwave oven (Sánchez-Pardo, Ortiz-Moreno, Mora-Escobedo, Chanona-Pérez, & Necoechea-Mondragón, 2008) while image analysis was used with fractals to record and quantify changes in dough structure as a function of temperature, mass loss and loaf height (Pérez-Nieto et al., 2010). The colour, crust browning and specific volume of batter was studied during baking of corn biscuits (Lara, Cortés, Briones, & Perez, 2011) and a mechanistic analytical model to obtain the evolution of temperature, moisture and air volume fraction of aerated food has been derived (Narsimhan, 2013). The effect of the dough rheology on the bubble formation and crumb structure in dough as well as gluten free dough has been addressed by several authors (Berta, Gmoser, Krona, & Stading, 2015; Chevallier, Della Valle, Colonna, Broyart, & Trystram, 2002; Dobraszczyk & Morgenstern, 2003; Martínez & Gómez, 2017; Scanlon & Zghal, 2001; Tunç & Kahyaoglu, 2016). Model batter systems have been used in order to determine the effect of sugar, fat and egg on starch gelatinisation and the viscoelastic properties (Hesso et al., 2015). The effect of resistant starch combined with enzymes (Altuna, Ribotta, & Tadini, 2016) and pea pod fibres with wheat bran (Fendri et al., 2016) on the rheology of bread dough were studied as well. Enzymes have been used to minimise the impact on rheology caused by high levels of starch granules damaged during milling (Barrera, León, & Ribotta, 2015). The

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impact of flour composition in terms of protein content and glutenin-to-gliadin ratio on the rheology of dough has been investigated experimentally (McCann, Le Gall, & Day, 2016) whereas a predictive numerical micromechanical model has been developed which treat dough as a particulate composite material (Mohammed, Tarleton, Charalambides, & Williams, 2013). Finally the rheological behaviour of various gluten free doughs was studied (Burešová & Kubínek, 2016) and they reported shear oscillatory measurements during a temperature ramp to simulate baking.

Despite the relatively large amount of work so far, the evolution of the microstructure during baking is still largely not understood, especially for realistic recipes which can be rather complex.

In the present study, a standard cheese cracker dough recipe is used to determine the effect that the microstructure has on the mechanical properties, which in turn contributes to the texture of the final product. During baking two effects are occurring simultaneously; the temperature increases and the microstructure evolves, which both influence the rheology of the dough. In an effort to decouple the two, mechanical tests were performed at room temperature on dough baked for various times and subsequently cooled to room temperature before testing. The tensile, compressive and simple shear properties are measured at different stages of baking. The microstructure is also observed using cryo-scanning electron microscopy techniques in order to investigate structural and mechanical changes occurring during baking. Finally, the dough rheology under dynamic heating was also measured. During the latter tests, both the changing temperature and the evolving microstructure affect the rheology simultaneously; rheology is important as the microstructure evolution will largely depend on the ability of the dough to deform.

2. Materials and methods

2.1. Dough preparation and baking

Cheese cracker dough was prepared using the recipe shown in Table 1, which also gives composition of protein, carbohydrates, fat and fibre for each ingredient. The dry ingredients, flour, salt, cheese and butter, were first combined together by pulsing in a 750 W food processor ('FPP220' Kenwood, UK). The cream, which was the only source of water in this recipe, was then added to the mixture and mixed at a speed of 118 rpm in a laboratory six-pin mixer ('200G Swanson Mixer/Special' from National Manufacturing Co., USA). The mixer achieved optimum dough development by stretching the dough between four planetary rotating pins and two stationary pins. The mixing torque and speed were recorded using a data acquisition device, 'NI USB-6009', controlled using 'LabVIEW 2014 14.0', both from National Instruments, UK. The optimum mixing time was found to be between 45 and 60 s. There was no decrease in torque at higher mixing times, indicating that there was no 'overmixed' mixing regime as reported in other dough systems (Dreese, et al., 1988a; Charalambides, Goh, Wanigasooriya, Williams, & Xiao, 2005; Xiao, Charalambides, & Williams, 2007). The mixed dough was rolled into sheets of nominally 6 mm thickness using a polytetrafluoroethylene (PTFE) roller. The dough was wrapped in cling film coated with paraffin oil in order to maintain its moisture content before testing.

Baking took place in a 'Welland WF 60' fan oven (Lenton, UK). For the baking profile study, cylindrical samples of dough of diameter 20 mm were placed in the centre of the preheated oven, on a steel baking tray, lined with greaseproof paper. For the microscopy study, partly baked dough was chilled immediately after removing from the oven using liquid nitrogen in order to 'freeze' its microstructure and stop the baking process. For all the mechanical tests, sheets of dough were baked, then left in the lab environment of 21 °C and 0.5 relative humidity to cool down to room temperature and appropriate samples were subsequently cut from the cooled sheets. More details about the rheological tests and microscopy studies are given in the following sections.

2.2. Cryo-scanning electron microscopy

A Hitachi S-3400N scanning electron microscope (SEM) fitted with a cryo-stage, 'Alto 2100' from Gatan, UK, was used to obtain images of freeze fractured dough samples. The dough samples were mounted onto a copper holder on the vacuum transfer device (VTD) using Tissue-Tek optimum cutting temperature (O. C. T.) compound from Sakura, Japan. The full process is described below.

The dough samples were immersed into liquid nitrogen slush at −210 °C, which was prepared by evacuating the slushing chamber first and then allowing the frozen nitrogen to melt, for approximately 15 s. The samples were then transferred under vacuum using the VTD into the cryo-preparation chamber, which was held at −158 °C and high vacuum of 4 Pa. They were then freeze fractured using a cooled surgical blade. Subsequently, the samples were etched by removing the water/ice on the surface via sublimation at −90 °C for 2 min (Mohammed et al., 2011) and sputter coated for 60 s with a thin layer of gold. A typical accelerating voltage of 5–15 kV and working distance of 11–14 mm was used.

2.3. Uniaxial compression

Uniaxial compression tests were performed to obtain the true stress-true strain behaviour. A sample with a diameter of 20 mm was made by punching the sheet of dough using a cylindrical die. The initial height of the unbaked dough was constant at 6 mm but the final height of the samples prior to testing was determined by the baking process and typically between 6 and 12 mm.

The tests were performed using an Instron 5543 universal testing machine with a 1 kN load cell at room temperature of 21 °C and constant true strain rates of 0.5 min^{-1}, 5 min^{-1} and 50 min^{-1}. In order to keep the true strain rate constant, the machine decreased the crosshead speed exponentially during compression. The poly(methyl methacrylate) (PMMA) loading platens were lined with PTFE sheets and lubricated using 0.5×10^{-3} m^2/s silicone oil from Sigma-Aldrich, UK. The load-displacement data output by the Instron and the measured geometry of samples were used to calculate the true strain, ε, and true stress, σ:

Table 1
Recipe and source of ingredients of the cheese cracker dough.

Ingredient	Amount	Protein (g/kg)	Carbohydrate (g/kg)	Fat (g/kg)	Fibre (g/kg)	Details
Wheat flour	128 g	126	685	14	31	Strong white bread flour, Wessex Mill
Parmesan cheese	50 g	330	5	284	05	Sainsbury's grated Parmigiano Reggiano D.O.P.
Unsalted butter	60 g	6	6	829	0	Sainsbury's unsalted English butter
Cream	60 g	33	21	180	5	Sainsbury's British single cream
Salt	3 g	N/A	N/A	N/A	N/A	Table salt