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A novel laboratory scale method for studying heat treatment of cake flour

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ABSTRACT

A lab-scale method for replicating the time–temperature history experienced by cake flours undergoing heat treatment was developed based on a packed bed configuration. The performance of heat-treated flours was compared with untreated and commercially heat-treated flour by test baking a high ratio cake formulation. Both cake volume and AACC shape measures were optimal after 15 min treatment at 130 °C, though their values varied between harvests. Separate oscillatory rheometry tests of cake batter at 80–100 °C exhibited similar behaviour to the baking tests. The gel strength parameter in the weak gel model, measured at 100 °C, was shown to correlate with flour quality and was identified as a possible alternative to test baking as a means of assessing flour quality after heat treatment.

1. Introduction

The UK cake market is worth more than £1bn in sales annually (www.talkingretail.com, 2009). Cake is a luxury food item, enjoyed for its sweet taste and tender eating quality. The latter is achieved by cake being a solid foam, and the development and solidification of this microstructure through the batter preparation and baking stages are critical to cake quality. Historically, cake contained sugar and liquid in equal quantity to flour (McGee, 2004; Indrani and Rao, 2008), but demand for sweet, moist cakes – particularly in the UK and USA – has led to increased proportions of sugar and liquid in commercial cake recipes. The vast majority of commercial recipes have a larger weight of sugar and/or liquid than flour (Premier Foods, personal communication). Such recipes are termed 'high ratio' and are defined as those containing a ratio of sugar-to-flour, or liquid-to-flour, in excess of 1 (McGee, 2004).

High ratio recipes tend to be sweeter, moister, more tender, and with a longer shelf life than other recipes. The disadvantage, however, is that the large proportions of sugar and liquid put stress on the structure-building components, namely flour and egg. Cakes produced with base flour (*i.e.* not heat treated) tend to decrease in volume towards the end of baking and subsequent cooling. In some instances the cake collapses, resulting in a dense or dipped product. Loss of volume and collapse are serious problems for cake manufacturers. Heat-treatment of the flour prior to baking helps prevents this collapse, giving improved final product volume and stability, whilst maintaining a sweet taste (Sahin, 2008).

Although there have been some previous studies on the influence of heat treatment on the physical and chemical characteristics of wheat flours (Guerrieri and Cerletti, 1996; Guerrieri et al., 1996; Ozawa and Seguchi, 2006; Ozawa et al., 2009), the effect of heat-treatment on batters, baking and cake quality is poorly understood, largely because the chemical and physical changes are hard to detect (Nicholas et al., 1974) and difficult to relate to individual factors such as starch nature and protein content. Niell et al. (2012) summarized the studies in this area and reported that heat treatment affects gluten extensibility and water absorption, starch gelatinization and cake structure. While the precise mechanism(s) are the subject of debate, the need for heat-treatment is clear, as without it less sugar and fat can be added to the recipe, compromising eating quality and shelf life (Premier Foods, personal communication).

In the UK the majority of cake flours are subjected to some form of heat-treatment prior to the cake baking process. Heat-treatment was first reported by Mangels in 1934 as a method of beneficially altering the properties of flour, and patents detailing industrial processes appeared in the 1960s (Doe and Russo, 1968). Heat-treatment was widespread in industry long before the phase out of the prior chlorination process in the early 1990s.

A typical industrial heat treatment process involves the following steps (Premier Foods, personal communication):

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Nomenclature

A_F	gel strength, weak gel model (Gabriele et al., 2001) (–)	$t_{contact}$	time of heat-treatment (min)
G'	elastic modulus (Pa)	T_f	temperature of flour during heat-treatment (°C)
G''	viscous modulus (Pa)	z	number of gel units, weak gel model (Gabriele et al., 2001) (–)
$\|G^*\|$	magnitude of the complex modulus (Pa)	$\|\eta^*\|$	complex viscosity (Pa s)
k_{T_1}	rate of reaction at temperature T_1 (s^{-1})	ω	frequency (rad s^{-1})
t_{130C}	effective treatment time at 130 °C (min)		

1. Pre-drying the flour to below 4 wt% moisture while raising its temperature to 125–140 °C.
2. Holding the flour for around 20 min in a series of heated screws at 125-140 °C.
3. Cooling the flour to halt the heat treatment.

Re-humidification after heat-treatment to 7 wt% moisture is necessary to minimise the evolution of heat (via hydration) during subsequent batter creation, and to produce a reliable product. An unavoidable consequence of hydration, however, is the formation of agglomerates, and so a final milling step is necessary to achieve the desired particle size distribution.

The optimal time and temperature for heat treatment in stage 2 can vary with harvest year as a result of annual variation in both wheat supply and properties. Hence the optimal conditions and grist have to be established each year, requiring a campaign of testing. Currently the only method of assessing the quality of heat-treated flour is to test bake, using a set laboratory recipe incorporating high levels of sugar and liquid, designed to test the robustness of the flour. Such tests are time consuming, require specialist operators, and are subject to inherent variability. Furthermore, assessment of the 'quality' of a cake is non-trivial. Parameters such as volume and height are recorded quantitatively, but aspects such as shape, evenness and texture are assessed qualitatively by a trained operator. Niell et al. (2012) studied heat treatment of a flour using a fluidized bed to deliver between 5 and 60 min of heat treatment at 120 °C and 130 °C. They assessed the effect of heat treatment by Brabender viscosity measurements, gluten extensibility, starch gelatinisation and test baking of Madeira cake. Quantifiable improvement in cake quality was observed and they reported an optimal heat treatment as 30 min at 130 °C. They did not report results for different harvests. Thomasson et al. (1995) heat treated flour by placing a layer of flour on a tray in an oven and reported an optimal treatment as 30 min at 125 °C. Different harvests were again not considered.

A more rapid and reproducible method of assessing the quality of flour heat-treatment is desirable. There is considerable interest in developing methods to replace test baking completely, or at least to give indicators of test baking performance in order to reduce the number of tests to be conducted. In particular, it is important that any methods are robust to changes in wheat properties over time, i.e. not just for a single harvest, and this has largely been ignored by previous work in the literature.

In this paper we describe a new protocol for replicating heat treatment of flour at the lab scale, aimed at controlling the time and temperature of treatment accurately, to produce flour of a similar quality to that produced commercially. In addition to its small scale, lab-scale heat-treatment eliminates the additional post-processing required in the industrial process, notably milling. Thus it allows the effect of heat treatment to be separated from the other processing effects inherent in the industrial process.

We then address two important issues in heat treatment:

1. The optimal process conditions for heat-treatment. The current time and temperature variables used in the industrial process generally produce good quality flour, but knowledge of the optimal conditions is desired for adjusting the process between harvests. Flour quality was assessed by test baking.
2. Development of a novel method of assessing flour quality. Test-baking is time-consuming, requires skilled operators and has inherent variability. A method is required that correlates well with baking performance but is quicker, simpler or more reproducible. Ideally such a method could be implemented at an industrial mill for quality control purposes. The method described here is based on estimates of batter strength estimated using the weak gel model interpretation of oscillatory shear testing (Gabriele et al., 2001). Meza et al. (2011) studied batter rheology at temperatures from 70 to 90 °C and reported that commercially heat-treated flours formed stronger gels in cake batter above the gelatinisation temperature than untreated flours, allowing them to support larger mechanical stresses.

The paper does not contain detailed analyses of flour chemistry and functionality, as the aim of the paper is to introduce the heat treatment method. Elucidation of the mechanisms responsible for the improvement in flour performance caused by heat treatment will require this information, in due course.

2. Materials and methods

2.1. Flours

Untreated flour, labelled 'base', and commercially heat-treated wheat flours were obtained from the Premier Foods mill at Selby, UK. Flours were obtained from three recent harvests. Their compositions are reported in Table 1. The flour sources were not disclosed for reasons of commercial confidentiality.

The particle size distributions of the base and heat-treated flours were determined by light scattering using a Coulter LS230 laser diffraction particle size analyser (Beckmann Coulter, Buckinghamshire, UK) fitted with a small volume module. Samples (~50 mg) were dispersed in isopropyl alcohol (20 mL) and sonicated using an Ultrawave U500 ultrasound bath (Ultrawave Ld., Cardiff, UK) for 1 min at room temperature to separate loosely connected particles. Laser diffraction measurements were interpreted using Mie theory, with a refractive index (RI) of 1.533 (Sevenou et al., 2002) and an opacity value (Im) of 0.01 (Coulter, 1994). The refractive index of the solvent (isopropyl alcohol) was 1.374. Almost all the particle sizes lay in the range 1–200 μm. All the flours exhibited a trimodal size distribution, with a smaller peak with respect to volume centred at 4 μm associated with fines, and modal peaks at 25 μm and 65 μm. The heat-treated flour exhibited a smaller number of particles in the third mode, which is attributed to the extra milling stage employed during its processing.

2.2. Ingredients

A model high-ratio cake recipe was used for test baking. The relative quantities of flour and water were adjusted for flour moisture