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Monitoring cake baking by studying different ingredient interactions: From a model system to a real system

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ABSTRACT

Cake batter is a complex matrix essentially composed of lipids, egg, sugar and flour. The baking process plays an important role in the structural, textural and physical properties of cakes, as in all bakery products. Knowledge of the interactions between the ingredients and the induced phenomena, such as starch gelatinization and complexation, protein denaturation and competition for water at the different stages of batter baking, can be used as the key quality control of the end-product “cake”. The aim of this work was to investigate in depth the interactions between the different constituents of the batter by differential scanning analysis and heating cell X-ray diffraction on model and real batter systems. The results show that ‘three ingredients’ model systems can explain the different phenomena occurring during the baking of cake batter (real system). In the presence of sugar and fat, in a limited water system, starch gelatinization takes place in two steps, the largest part being combined with protein denaturation at high temperature.

1. Introduction

Baking is a simultaneous heat and mass transfer process, which causes a gradual increase in temperature and dehydration of the product. This process determines the kinetics of a series of complex physical and chemical reactions (i.e. volume increase, starch gelatinization, protein denaturation and surface browning). In order to control and optimize baking, these critical phenomena, which determine the quality of the final product, should be clearly identified (Zanoni, Peri & Bruno 1995).

Starch gelatinization is a key phenomenon during baking representing the major ingredient in bakery products; it contributes to the unique textural and structural characteristics of the products (Zanoni, Schiraldi & Simonetta 1995). The gelatinization temperature depends upon the botanical origin of starch and on the amount of water present, pH, and types and concentrations of salt, sugar, fat and protein in the recipe. In addition, the degree of cross-linking of the amylopectin, the amount of damaged starch granules, amylose and amylopectin contents, as well as the derivatization technology used, can play a role (Cruz-Orea, Pitsi, Jamée, & Thoen, 2002; Fredriksson, Silverio, Andemon, Eliasson & Aman, 1998; Hermansson & Svegmark, 1996; Ubwa, Abah, Asemave & Shambe, 2012). A study of the effect of moisture content on the thermomechanical behavior of concentrated waxy cornstarch/water preparations was carried out by Rolée, Chiotelli, and Le Meste (2002). They found that the critical moisture content for waxy cornstarch that caused a radical change in starch behavior, both at room temperature and during heating, ranged between 50 and 55%.

The fact that sugar increases the temperature at which starch gelatinizes has been documented by many authors (Hyang Aee, Nam Hie, & Nishinari, 1998; Perry & Donald, 2002; Prokopowich

Abbreviations: F, flour; E, egg; S, sugar; FA, fat; W, water; x, flour percentage on a dry basis; y, egg percentage on a dry basis; z, sugar percentage on a dry basis; a, fat percentage on a dry basis; b, percentage of total water content (always measured on a wet basis); μDSC, microcalorimetry; FA, fat melting (endotherm 1); FA′, fat melting (endotherm 2); G, starch gelatinization; M1, starch melting; E*, egg protein denaturation; M2, amylose–lipid complex melting; To, onset temperature; Tp, peak temperature; TDB, total dry basis.

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& Biliaderis, 1995; Torley & Van der Molen, 2005). Small solutes, such as sugar and salt, decrease water activity (Chinachoti, Kim-Shin, Mari, & Lo, 1991; Ratnayake, Otani, & Jackson, 2009). Spies and Hoseney (1982) reported effects not only on water activity but also on the interaction of sugar with starch chains in the amorphous areas; this increased the energy required for gelatinization and, consequently, the temperature of gelatinization. On the other hand, sugars act to stabilize proteins by increasing the denaturation temperature (Garrett, Stairs, & Annett, 1988; Kulmyrzaev, Bryant, & McClements, 2000). An increase in onset (To) and peak (Tp) denaturation temperatures was found by Nafchi, Tabatabaei, Pashania, Rajabi, and Karim (2013). This was associated with an increase in the protein stability of ovalbumin and ovotransferrin when the sugar concentration in egg-white protein gels was increased.

Starch gelatinization is influenced by the presence of another major ingredient in baking products, i.e. protein originating from gluten or egg. Proteins compete with starch for the available water in the system and affect its gelatinization. Mohamed and Rayas-Duarte (2003) proved that protein extract and gluten interact differently with starch and influence its gelatinization parameters and water evaporation. The effect of flour components and dough ingredients on starch gelatinization was studied by Ghiasi, Hoseney, and Varriano-Marston (1982). They found that, in a limited water system like dough, gluten severely restricts migration towards starch granules, which explains the rise in the gelatinization temperature. The interactions between starch gelatinization and egg albumen denaturation were studied in solutions by Singh and Roos (2005) and Wongsasulak et al. (2006). Recently, Wilderjans, Luyts, Goesaert, Brijs, and Delcour (2010) used a model approach to explore starch and protein functionality in a pound cake system. They concluded that the combination of a protein network, formed during baking, with a starch gel, formed during cooling, makes up the crumb cell walls and determines cake quality.

During heating processes, starch granules swell and amylose leaches out of the swollen starch granules. Seyhun, Sumnu, and Sahin (2005) showed that there was more amylose leached in control cakes during microwave baking than during conventional baking. Some small molecules (i.e. aroma compounds or fatty acids) may then form amylose complexes (Biais, Le Bail, Robert, Pontoire, & Buléon, 2006; Fanta, Shogren, & Salch, 1999; Jouquand, Ducruet, & Le Bail, 2006). Zobel, Young, and Rocca (1988) found the formation of crystalline V-type complexes of amylose with granule fatty acids of normal maize starch caused by heating. This amylose–lipid complex occurs after gelatinization and affects the rate of retrogradation (Fredriksson et al., 1998). In more detail, monoglycerides are able to form helical inclusion complexes with amylose. This prevents the amylose and, to some degree, amylopectin from recrystallizing. Furthermore, it is known that the effect of an emulsifier on different types of starch is to lower retrogradation (Eliasson & Ljunger, 1988). This effect was found to be greater at high temperatures.

In cakes, Marcotte, Sablani, Kasapis, Baik, and Fustier (2004) found that starch gelatinization in the presence of other cake ingredients can be used as a quality control parameter in the baking process. The degree of starch gelatinization in cakes by different baking oven was studied by Sakiyan et al. (2011). These authors found that the degree of starch gelatinization was increased by combining infrared with microwaves heating which was then close to conventional baking. However, few studies investigating the batter-crumb transformation during baking in complex systems such as cake batters were found.

Cakes are complex systems and cake firming is driven not only by starch retrogradation, as in the case of bread, but also by other important interactions due to other cake ingredients (eggs, oil/lipids and sugar). In this work, the interactions between four principal ingredients (flour, egg, sugar and fat) in a pound cake recipe are investigated first ingredient by ingredient, and then by considering the ingredients two by two until a complete and complex model with all the ingredients together is reached. The results are used to explain what happens in a simple relevant industrial pound cake recipe during baking. All tests were carried out by microcalorimetry. A heating cell X-ray diffraction was used to consolidate the results obtained on the batter phase transitions.

2. Materials and methods

2.1. Materials

Wheat flour (14.8% water content, 9.9% protein, 1.1% fat, 71.5% starch and 0.4% ash; on wb) was supplied by Giraudineau (France), and whole liquid eggs (0.8% minerals, 12.1% protein, 10.2% fat and 0.8% carbohydrates; on wb) were purchased from Ovoteam (France). Fat consisted of rapeseed oil (70%) and anhydrous milk fat (30%) supplied by Corman (Belgium). Sugar (sucrose) was purchased from Saint Louis (France). Baking powder (sodium bicarbonate) was supplied by Brenntag.

2.2. Methods

2.2.1. Model batter system preparation

Model systems were prepared by hand mixing with a spatula for 5 min four principal ingredients (flour, egg, sugar and fat) in the same proportion as in real batter, starting ingredient by ingredient, and then two by two until a complete and complex model system with all ingredients was reached. The different model systems were prepared in a limited water system (30% water content) and represented by the following formula (1):

$$\mathbf{F_x E_y S_z FA_a W_b} \quad (1)$$

where F is flour, E is egg, S is sugar, FA is fat and W is water. x, y, z, a were calculated on dry matter ($x + y + z + a = 100$) and b represents the total water content (always measured on a wet basis). The ingredients were added while respecting the recipe of the reference cake.

2.2.2. Real batter preparation

The batter ingredients were mixed in a multi-stage mixing, as described in Hesso, Loisel, Chevallier, and Le-Bail (2014), using a KitchenAid mixer (KSM90, KitchenAid, St. Joseph, MI) with two mixing speeds (speed 6 for 2 min and speed 8 for 3 min). First, sugar, whole liquid eggs and fat were placed in the stainless steel bowl of a KitchenAid mixer and mixed. Next, wheat flour and baking powder were added and the whole was remixed.

2.2.3. Cake baking

Real cake (industrial) baking was performed in a ventilated oven at 180 °C for 15 min as described in Hesso et al. (2014). After baking, the cake was cooled to room temperature.

Freshly prepared samples were kept in a plastic container with a lid to prevent moisture loss. Water content was measured by drying at 105 °C overnight for model batter systems, real batter and baked cake. The measurements were made in triplicate.

2.2.4. Differential scanning calorimetry measurements

700-800 mg of sample was placed in stainless steel pans and 300–600 mg of water was placed in the reference pan. Pans were heated at a rate of 1.2 °C/min from 20 to 120 °C (both ways) by using the SETARAM microcalorimeter (μDSC) VII and III (France). Two