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Rational design to develop a non-reactive model food imitative of a baked cereal product by replacing the functional properties of ingredients

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ABSTRACT

A model product, non-reactive in terms of Maillard and caramelization reactions, and with a structure and manufacturing process imitative of a sponge cake, was developed. A rational formulation design was used to identify the functional properties of the ingredients at each step of the process. Reactive ingredients (*i.e.* eggs, sucrose and flour proteins) were replaced by cellulose derivatives (hydroxypropylmethylcellulose and methylcellulose) to provide the main functionalities of the ingredients removed (foaming, thickening and gelling). Different properties of a real sponge cake were selected as targets to be reproduced in the model product: apparent viscosity, batter density before baking and homogeneity of the crumb cellular structure after baking. The concentrations of cellulose derivatives were determined to reach 1.4 Pa s at 270 s^{-1}, the mixing time was selected in order to incorporate 56% (w/w) of air in the batter, and the types of cellulose derivatives were chosen to obtain homogeneous cellular structures. The use of HPMC alone led to cellular structures containing chimneys. The addition of a certain proportion of MC was necessary to obtain model cakes with homogeneous and fine crumb cellular structures. The sponge cake density was correlated with the HPMC and MC concentrations and ratios, both being linked to the ability of the batter to trap bubbles and prevent coalescence during baking. A colorimetric analysis of the crust confirmed the non-reactivity of the product during baking. The resulting product could be used as a realistic sponge-cake type matrix to study the reactions occurring throughout the processes.

1. Introduction

Semi-moist baked cereal products such as sponge cake contain eggs, fat, sugar and wheat flour. These ingredients play important roles in the elaboration of both cellular structure and texture, and in the development of sensory and nutritional properties. During processing, chemical reactions such as lipid oxidation, the Maillard reaction and caramelization also occur and contribute to the development of colour and flavour, and therefore to global product quality and consumer preferences. They are also responsible for certain negative effects, such as a loss of the nutritive value of proteins and the development of potentially toxic newly formed compounds (Martins, Jongen, & van Boekel, 2001). Because of the complexity of their formulation and the impact of process parameters, the properties of sponge cakes are difficult to master. Industrial conditions for the production of baked cereal products are mainly based on the experience of technologists (Lostie, Peczalski, Andrieu, & Laurent, 2002) and do not include an optimization of the balance between the desired and undesired effects of the Maillard reaction. It would therefore be of great interest to obtain scientific knowledge of the reactions that occur during soft cake production in order to optimize recipes and processes.

However, study of the reactions that occur during the baking of cereal products remains challenging. Many of these reactions are only partially understood (Chang, 2006). All formulations containing amino acids, peptides or proteins (with an amine function) and a reducing sugar (with carbonyl groups) will lead to Maillard and caramelization reactions. In a classic sponge cake recipe, only starch and water can be considered as non-reactive ingredients. Furthermore, most of the reaction pathways that have been described in the literature were highlighted in simplified liquid systems (Hodge, 1953; Kroh, 1994; Martins & Van Boekel, 2005),

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and cannot be easily transposed to complex solid systems. Fehaili et al. (2008) proposed a global approach to extract an apparent identifiable reaction scheme in order to obtain a reliable representation of the systems when considering the information actually available. This is based on theoretical knowledge of the system and on the kinetics data relative to the reactivity of a real sponge cake acquired under perfectly controlled baking conditions. An original oven was specially developed for that study. It was thus possible to achieve homogeneous and controlled thermal treatments, to collect samples without disrupting the process, and to monitor dynamically the emission of volatile compounds in the oven during baking (Fehaili, Courel, Rega, & Giampaoli, 2010). However this approach requires further development so that it can discriminate between reaction pathways due to the complexity of the product and the numerous possible interactions between ingredients. One method to understand the specific role of each constituent in the different reaction pathways would be to use a simplified solid system and master the incorporation of reactive ingredients. However, in order to elaborate a model cake with an aerated cellular structure that mimics the sponge cake and containing no reactive ingredients, information is necessary at each step of the process regarding the functional properties of the constituents which need to be removed.

The production of a sponge cake consists in the formation of a solid viscoelastic foam through several steps of processing: mixing, during which two steps of foaming can be distinguished and baking. Egg proteins and lipids, sucrose and wheat proteins play a major structuring role both during foaming and baking. During foaming, egg proteins have interface stabilizing properties (Arozarena, Bertholo, Empis, Bunger, & Sousa, 2001; Kamat, Lawrence, Hart, & Yoell, 1973), while egg lipids have emulsifying properties (Kamat et al., 1973; Kiosseoglou, 2003). Sucrose (Baeva, Panchev, & Terzieva, 2000; Yang & Foegeding, 2010) and wheat flour (Choi & Baik, 2013; Moiraghi, de la Hera, Pérez, & Gómez, 2012) have mostly thickening properties. In practice, the mixing process is divided into two steps of foaming. First, eggs and sucrose are mixed at high speed in order to form a very aerated foam. Flour is then added at a lower mixing speed in order to disperse and hydrate the flour grains while minimizing foam disruption. When put into contact with water, proteins and pentosanes swell and starch granules absorb some water resulting in a marked increase in batter viscosity. The shear-thinning rheological behaviour of a batter is useful to form the foam (Chesterton, de Abreu, Moggridge, Sadd, & Wilson, 2013; Turabi, Sumnu, & Sahin, 2008). At high speed mixing, this shear-thinning behaviour also facilitates the incorporation of air bubbles in the batter because of its low viscosity. At rest, the high viscosity of the aerated batter enables the retention of air bubbles. It is therefore essential to stabilize the foam to prevent further creaming, coalescence or gas diffusion between bubbles. The viscosity of the continuous phase, the adsorption of proteins at the air/batter interface, and the size and number of bubbles all influence the structure and volume of the final cake (Bennion & Bamford, 1997). Most of the structural properties of the final product are directly or indirectly determined by the mixing step (Haegens, 2006). The bubbles that remain at the end of mixing will determine the cell structure during and after baking. Baking is responsible for physicochemical modifications induced by heat and mass transfers which lead to transformation of the aerated batter into a porous, cellular, structured and expanded gel (Kiosseoglou, 2003; Mizukoshi, Maeda, & Amano, 1980; Moiraghi et al., 2012). Expansion during baking, and the final structure of the product, are determined by both process parameters and the rheological properties of the batter, which in turn depend on the behaviour and interactions between compounds (Chevallier, Della Valle, Colonna, Broyart, & Trystram, 2002; Pareyt, Wilderjans, Goesaert, Brijs, & Delcour, 2008). During baking, the thermo-gelling properties of the constituents are preponderant. A substantial expansion of bubbles occurs, with gradual opening of the internal structure which may result in a slight shrinking of the cake if the crust has not yet been formed when opening is generalized (Lostie et al., 2002). Several functional properties of the ingredients contribute to cellular structuring at this stage. Egg proteins (Arozarena et al., 2001; Bennion & Bamford, 1997; Kamat et al., 1973; Kiosseoglou, 2003) and wheat flour proteins (Choi & Baik, 2014) have gelling properties. Gelation starts within the range 55–75 °C (Anton, Nau, & Lechevalier, 2009; Kovacs, Fu, Woods, & Khan, 2004). Wheat starch granules gelatinize i.e. absorb a large amount of water and swell, at a temperature of around 63 °C in the absence of sucrose (Abdel-Aal, 2009; Biliaderis, 2009). Sucrose in the proportion involved in a cake recipe, can increase the gelatinization temperature by about 10–15 °C (Baeva et al., 2000; Hicsasmaz, Yazgan, Bozoglu, & Katnas, 2003; Mizukoshi, Kawada, & Matsui, 1979; Shelke, Faubion, & Hoseney, 1990).

Most of the ingredients involved in foam formation and stabilization during mixing, and in cell growth and crumb setting during baking, affect lipid oxidation, the Maillard reaction and caramelization. The aim of the present study was to develop a model product that imitated a real sponge cake structure but was non-reactive regarding these reactions. Removing all the reactive ingredients led to the challenge of developing a solid foam without eggs, sucrose and wheat proteins, using the same manufacturing process. An approach based on analysing the functional properties to be replaced at the different steps of cake making was applied in order to select non-reactive substitutes. As they were used in a concentrated system containing more than one ingredient, it was necessary to verify the effectiveness of their contributions, to adjust the concentrations on the basis of their functional properties in comparison to real sponge cake ones. The resulting properties of the model batter and cakes were characterized and discussed by comparison with the reference sponge cake and functional properties of the ingredients in simpler systems.

2. Materials and methods

2.1. Materials

2.1.1. Reference sponge cake

The reference sponge cake (recipe adapted from Pozo-Bayón, Guichard, & Cayot, 2006) contained liquid whole eggs (Ovipac, Ovoteam, Locminé, France), sucrose (Tereos, Lille, France), and wheat flour (Grands Moulins de Paris). Ingredient proportions are given in Table 1. No fat was added.

The water, protein, starch and ash contents of the eggs, flour and sucrose are also shown in Table 1. Protein content was measured in the eggs according to the official AOAC method 925.31 with a conversion factor of 6.25, and in flour according to the ISO norm 20483:2013. The starch content in the flour was measured according to NF norm V18 121. The ash content in flour was measured according to AOAC norm 923.03, while the water content in flour was measured according to NF norm V03 707. The water content in

Table 1
Proportions and composition of the ingredients in the reference sponge cake.

Ingredients	Proportions (%, w/w)	Contents (g/100 g ingredient)			
		Water	Protein	Starch	Ashes
Wheat flour	26.3	15.3	10.5	70	0.5
Liquid whole eggs	47.4	74.1	11.4	N/A	–
Sucrose	26.3	N/A	N/A	N/A	–