Functionality of Several Cake Ingredients: A Comprehensive Approach

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Abstract

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The roles of some cake ingredients – oil, a leavening agent, and inulin – in the structure and physicochemical properties of batter and cakes were studied in four different formulations. Oil played an important role in the batter stability, due to its contribution to increasing batter viscosity and occluding air during mixing. The addition of the leavening agent was crucial to the final height and sponginess of the cakes. When inulin was used as a fat replacer, the absence of oil caused a decrease in the stability of the batter, where larger air bubbles were occluded. Inulin dispersed uniformly in the batter could create a competition for water with the flour components: gluten was not properly hydrated and some starch granules were not fully incorporated into the matrix. Thus, the development of a continuous network was disrupted and the cake was shorter and softer; it contained interconnected air cells in the crumb, and was easily crumbled. The structure studies were decisive to understand the physicochemical properties.

Keywords: fat replacement; inulin; physical properties; structure

Bakery products constitute one of the most consumed foods in the world. Among them, cakes are popular and are associated in the consumer's mind with a delicious sponge product with desired organoleptic characteristics (Matsakidou *et al.* 2010). The physicochemical properties of cakes are largely dependent on the batter and cake structure. Therefore, understanding the internal macro- and microstructures of bakery products is essential (Turabi *et al.* 2010). Cake batter is a complex emulsion and foam system. Flour, milk, fat, sugar, eggs and the leavening agent are the main ingredients used in its elaboration; each ingredient has an important function in the cake structure. For that reason, several microstructural techniques were applied in this work to correlate the batter and cake structures with the physicochemical properties. Also, image analysis and quantification of the relative features were applied as they are the basis of the modern food microscopy (Turabi *et al.* 2010). The objective of this study was to understand the functionality of oil and inulin as structural ingredients of the sponge cake. The role of the leavening agent was also evaluated as it is an ingredient which contributes to the formation of the proper structure. For this purpose, four different formulations were examined, with or without the inclusion of oil, the leavening agent, and inulin.

MATERIAL AND METHODS

Ingredients. The ingredients used in the preparation of the cake batters were: wheat flour (Harinera Belenguer, S.A., Valencia, Spain; composition provided by the supplier: moisture ≤ 15%, proteins ≥ 10% s.s.s., ash ≤ 0.6% s.s.s., dry gluten ≥ 10.8%);

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Table 1. Formulations of the different batters (B) and cakes (C) (% in wheat flour basis)

Ingredients	B1/C1	B2/C2	B3/C3	B4/C4
Wheat flour	100	100	100	100
Egg yolk	27	27	27	27
Egg white	54	54	54	54
Skimmed milk	50	50	50	50
Sugar	100	100	100	100
Sunflower oil	0	46	46	0
Frutafit HD®	0	0	0	14.5
Sodium bicarbonate	0	0	4	4
Citric acid	0	0	3	3
Salt	1.5	1.5	1.5	1.5

sugar (Azucarera Ebro, Madrid, Spain); liquid pasteurised egg white and yolk (Ovocity, Llombay, Spain); skimmed milk (Puleva Food, Granada, Spain); refined sunflower oil (Coosol; Coosur S.A., Jaen, Spain); inulin Frutafit HD® of average chain length 8–13 (Sensus, Roosendaal, the Netherlands); sodium bicarbonate and citric acid (A. Martinet, Cheste, Spain); salt.

Batter and cake preparation. Four batters (B1, B2, B3, and B4) were prepared as given in Table 1. The batters were prepared according to Baixauli *et al.* (2008). Promptly, within 5 min after the end of the batter mixing, the batter was analysed.

For the preparation of the cakes, 800 g of batter were placed in a Pyrex baking pan (diameter 20 cm) and baked at 160°C for 40 min in a conventional oven (2CF-3V "Elegance"; Fagor, Guipuzkoa, Spain) preheated to 160°C during 20 minutes. Four cakes (C1, C2, C3, and C4) were obtained, corresponding to the batters formulations showed in Table 1. The cakes were kept at room temperature for 1 h and then analysed. All the batters and cakes were prepared in triplicates.

Apparent viscosity. The viscosity of the batter was determined using Haake Viscotester 6 R Plus (Thermo Scientific, Walthman, USA) equipped with spindle 4 at 6 rpm. The measurements were performed in duplicates.

Microstructure of batters. Confocal laser scanning microscopy (CLSM), light microscopy (LM), and image analysis of batter bubbles were performed according to the methods described by Rodríguez-García *et al.* (2012).

Weight loss during baking. The weight loss (WL%) during baking was calculated by using the following equation (Sumnu *et al.* 2005):

$$WL\ (\%) = (W_{batter} - W_{cake}/W_{batter}) \times 100$$

where: W – weight (g)

Cake height. The maximum cake height was measured in the cross section of the product using the software ImageJ (National Institutes of Health, Bethesda, USA). The baked product was cut with a stainless steel knife and photographed with a digital camera (E-510 Olympus, Hamburg, Germany). The measurements were performed in triplicates.

Image analysis of cellular structure of the crumb. The cakes were cut vertically with a stainless steel knife into 4 slices of 15 mm thickness. The cut side of each slice was scanned using a scanner (Epson Perfection 1250; Epson America Inc., Long Beach, USA).

The scanned images were analysed using the software ImageJ. The image was cropped in a 50 × 50 mm section, on which the analysis was performed. The cell area (mm^2) and total cell area within the crumb (%) were calculated. The data were obtained by measuring cells in twelve different images for each formulation.

Cake texture. The texture profile analysis (TPA) was carried out according to Sanz *et al.* (2009) with slight modifications. The test was performed in four cubes (40 mm side), the strain was 40% of the original cube height, and a 50 mm diameter aluminum plate (P/50) was used. The parameters obtained from the curves were hardness, adhesiveness, springiness, cohesiveness, and chewiness.

Cryo scanning electron microscopy (Cryo-SEM). Cryo-SEM studies of the crumbs of the different cakes were carried out according to the method described by Llorca *et al.* (2007).

Statistical analysis. Analysis of variance (ANOVA) was performed on the data using the Statgraphics Plus 5.1 software package (Statistical Graph Co., Rockville, USA). Least Significant Difference (*LSD*) Fisher's test was used to evaluate the mean values differences ($P < 0.05$).

RESULTS AND DISCUSSION

Batter – physicochemical properties and structure

Apparent viscosity. There were significant differences between all batter viscosity values (Table 2). B2 had a significantly ($P < 0.05$) higher apparent viscosity values than B1, while B3 was even more viscous ($P < 0.05$). The increase in viscosity in B2

Table 2. Mean values of apparent viscosity of batters (B1, B2, B3, and B4), weight losses during baking and heights of the cakes (C1, C2, C3, and C4)

Physical parameters	B1/C1	B2/C2	B3/C3	B4/C4
Apparent viscosity (mPa·s)	7030.00^{a} (28.28)	8780.00^{b} (254.56)	11425.00^{c} (190.92)	10730.00^{d} (84.85)
Weight loss (%)	12.14^{a} (1.19)	8.67^{b} (0.70)	6.67^{c} (0.68)	7.76^{bc} (1.03)
Height (cm)	2.60^{a} (0.05)	1.86^{b} (0.19)	12.31^{c} (0.46)	8.74^{d} (0.40)

Values in parentheses are the standard deviations; means in the same row without a common letter are significantly different ($P < 0.05$) according to the *LSD* multiple range test

and B3, in comparison to B1, was caused by the addition of sunflower oil. Oil in B4 was replaced by Inulin HD®, a polysaccharide that easily disperses in the aqueous phase, and acts as fat mimesis imparting viscosity as observed previously by Akalin and Erisir (2008). However, B4 apparent viscosity values were significantly ($P < 0.05$) lower than those of B3, thus the inulin addition did not increase the batter viscosity as much as the oil did.

Confocal laser scanning microscopy (CLSM). The distribution of ingredients in cake batters is shown in Figure 1. A lipoprotein matrix was observed in B1 consisting of protein and fat (mainly contributed by eggs and flour) and starch granules within the matrix.

The oil was observed in B2 and B3, stained with Nile Red, as green globules. Some small oil globules could be observed around the air bubbles. These oil globules located at the interface matrix-air could increase the bubble stability. Moreover, they could provide some of the physical properties, that several authors have stated for solid fats, such as stabilising air bubbles and improving gas retention (Mousia *et al.* 2007).

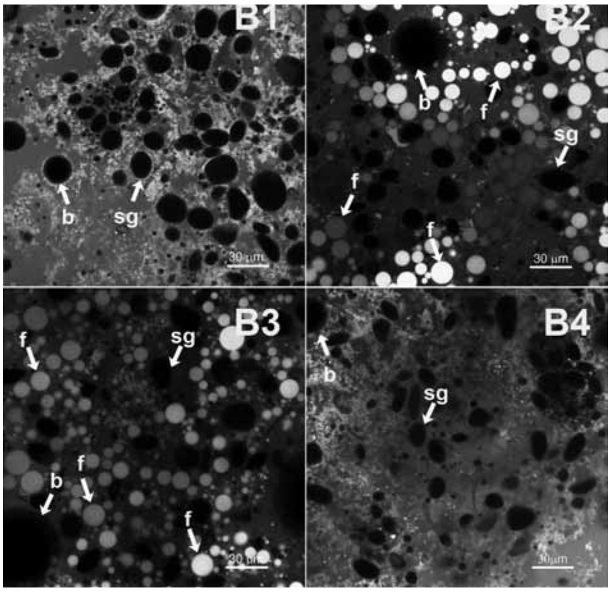

Figure 1. Confocal Laser Scanning Microscopy (CLSM). Batter images (B1, B2, B3, and B4). Arrows show sg: starch granule, b: air bubble, f: fat globule (magnification 60×)

B4 showed inulin homogenously dispersed in the lipoprotein matrix where the starch granules were embedded.

Light microscopy (LM) and image analysis of the air bubbles. The distribution and size of bubbles can be compared in the micrographs shown in Figure 2. The bubbles in B1 were small and clustered together. This clustered distribution could be due to the low viscosity of B1 that enabled the bubbles mobility throughout the batter. The addition of oil in B2 and B3 affected the stability of the batter and enabled a homogenised distribution of air (Figures 2c and 2e). Hicsasmaz *et al.* (2003) reported that an even distribution of bubbles within the cake batter is a function of the fat. B1, B2, and B3 contained a narrow size distribution of small air bubbles (Figures 2b, 2d, and 2f). B4 had a wider range of bubble sizes and larger bubble areas. This batter contained no oil, which is one of the components that act as stabilising air bubbles.

Sponge cakes – physicochemical properties and structure

Weight loss during baking (WL) and cake height. Table 2 shows the weight loss during baking. In B1 and B2, the low batter viscosity allowed bubble movement increasing the gas diffusion to the external surface and water evaporation. So, a large volume of gas was created leaving behind large central holes (Figure 3, C1 and C2) and increasing the WL. Similar results were observed by Turabi *et al.* (2010) in rice flour cakes prepared with different types of gum, where in low apparent viscosity batters the air bubbles could easily rise to the surface and get lost into the atmosphere. However, the weight

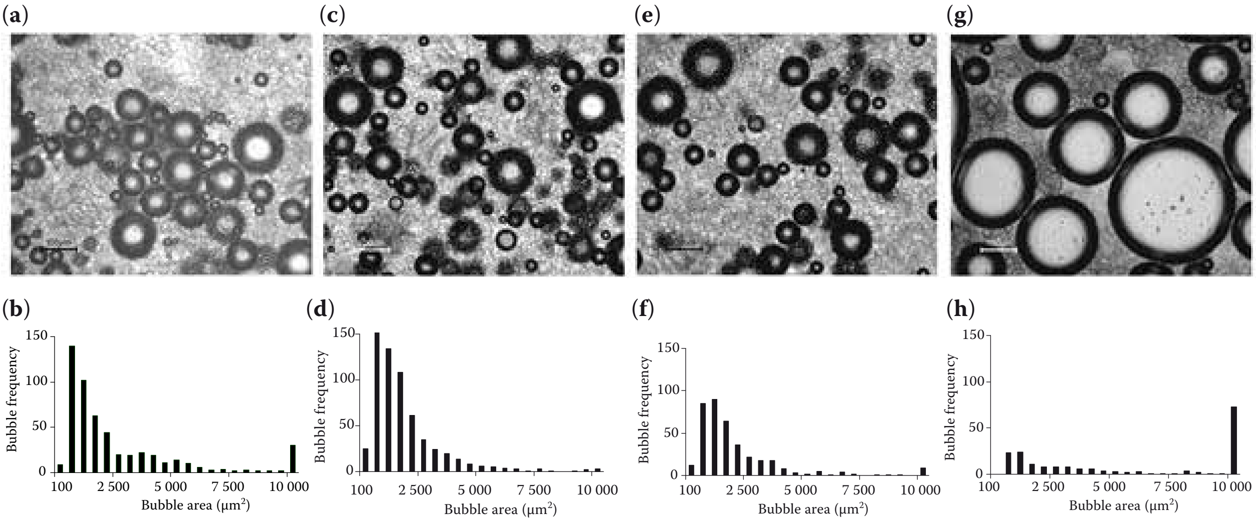

Figure 2. Batter microstructure. (a), (c), (e), and (g) LM images for batters B1, B1, B3, and B4, respectively. (b), (d), (f), and (h) bubbles size distribution histograms of batters B1, B2, B3, and B4, respectively (magnification 10×)

loss during baking was significantly higher in B1 ($P < 0.05$) than in B2 where, according to the pore-sealing hypothesis, the fats seal the pores in the structure to retard the escape of gas (Mousia *et al.* 2007).

B3 revealed a significantly lower weight loss ($P < 0.05$) than B1 and B2. In addition, B3 had a higher standing height than B1, B2, and B4 (Table 2). These results could be due to the leavening agent effect during the baking expansion and a better gas retention. These results were in concordance with those by Sanz *et al.* (2008) who suggested that the batter viscosity has an important effect on the bubble incorporation and movement which are considered controlling factors in the final cake volume.

B4 did not significantly differ ($P < 0.05$) in WL from B3, due to the water binding capacity of carbohydrate-based fat replacers. However, the lower apparent viscosity of B4, as compared with that of B3, and the large bubble size variation in B4 led to a significantly lower cake height ($P < 0.05$). These results were in accordance with other studies (Zahn *et al.* 2010) in which muffins with 50% of fat replaced with inulin showed a volume reduction without affecting significantly the mass loss during baking.

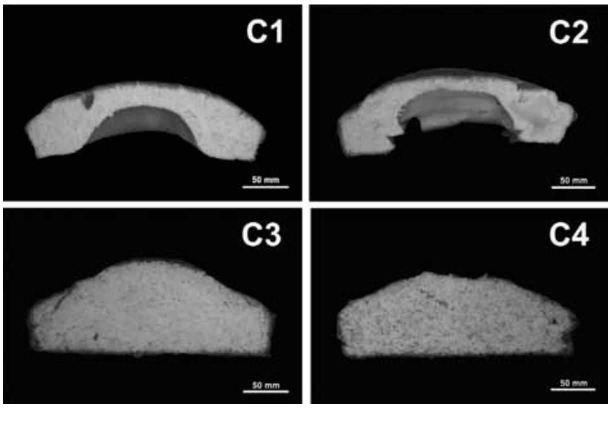

Figure 3. Appearance of the sponge cakes C1, C2, C3, and C4 (digital photographs of the cakes)

Image analysis of the cellular structure of the crumb. The complexity and heterogeneity of the cake structure mean that the physical properties differ greatly from one cake to another. In our study, the crumb structures were very different between the four types of cake (Figure 3). C1 and C2 corresponded to the model formulations, in which the leavening agent is not added, and so the development of the cake was limited. As C3 and C4 corresponded to the fully developed cakes, our work focuses on the analysis and comparison of C3 and C4 in this and the following sections.

Figure 4a shows the scanned and binarised images of C3 and C4; the cell area distribution histograms are shown in Figure 4b. Moreover, quantitative information in terms of the cell area and total cell area within the crumb were obtained from the binarised images using image analysis (data not shown).

There were significant differences ($P < 0.05$) in the cell areas, as well as the total cell areas within the crumbs – with the highest values corresponding to the cake made with inulin (C4). As stated before, fat replacement by inulin in B4 resulted in the occlusion of larger bubbles, which could expand more, and had more mobility. Thus, large interconnected cells and crack-like diffusion pathways dominated C4 structure as seen in Figure 4. As Kocer *et al.*

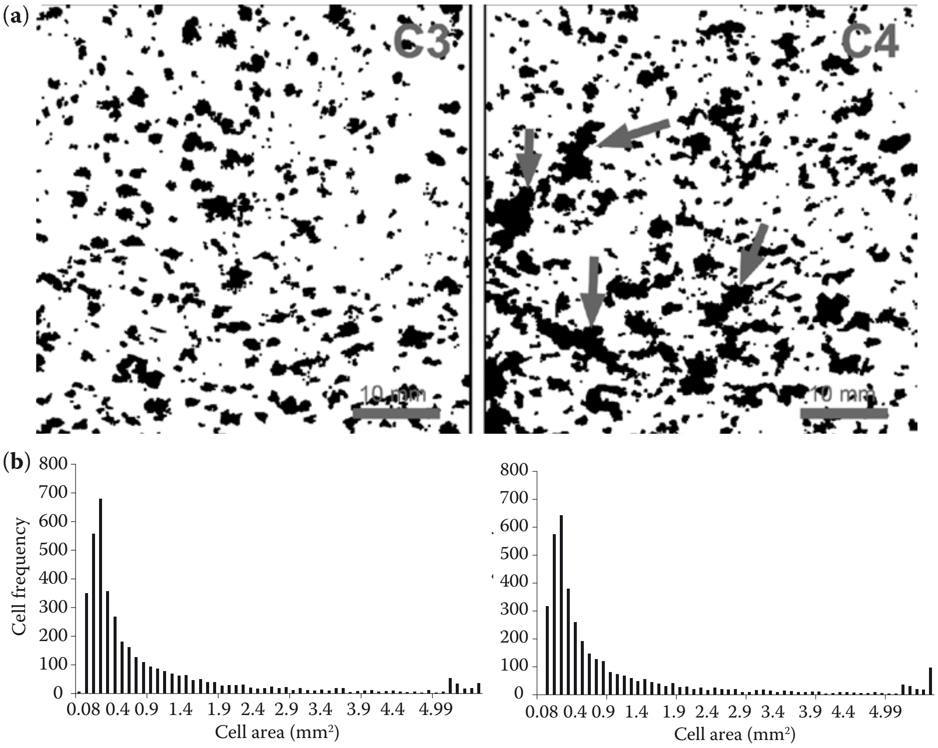

Figure 4. Cellular structure of crumb cakes C3 and C4. (**a**) Binarised images of scanned crumbs (arrows: interconnected air cells); (**b**) Cell size distribution histograms

(2007) showed, a higher mobility of the gas phase enhanced the formation of diffusion pathways.

Texture profile analysis (TPA)

TPA parameters are shown in Table 3. The incorporation of inulin and oil absence significantly decreased ($P < 0.05$) the crumb hardness. This result could be related with the cell crumb structure of C4: a higher percentage of the cell area and diffusion pathways. C4 was more adhesive; fructan molecules during baking were involved in caramelisation and Maillard reactions; thus, some products of these reactions would confer adhesiveness not only on the internal structure, but also on the external surface.

Table 3. Mean values of texture profile analysis parameters of cakes C3 and C4

TPA parameters	C3	C4
Hardness (N)	8.73^{a} (2.31)	6.7^{b} (1.32)
Adhesiveness (N·s)*	0.01^{a} (0.01)	0.04^{b} (0.03)
Springiness	0.85^{a} (0.01)	0.85^{a} (0.02)
Cohesiveness	0.69^{a} (0.03)	0.72^{b} (0.02)

Values in parentheses are the standard deviations; means in the same row without a common letter are significantly different ($P < 0.05$) according to the *LSD* multiple range test; *absolute values

C3 and C4 revealed similar springiness values. Significantly higher values of cohesiveness were obtained for C4 ($P < 0.05$). The uneven cell crumb structure where large air cells and compact crumb areas were found, gave this product higher cohesiveness and density. C4 was significantly less ($P <$ 0.05) chewy than the control, despite being less hard. This observation indicates that the structure was more compact and less aerated than the control.

Scanning electron microscopy at low temperatures (Cryo-SEM). The differences between cakes C3 and C4 microstructures can be seen in the micrographs obtained by Cryo-SEM technique (Figure 5).

The C3 structure was mainly formed by a well developed and hydrated protein network, where other components such as partially gelatinised starch granules were embedded. The oil acted as

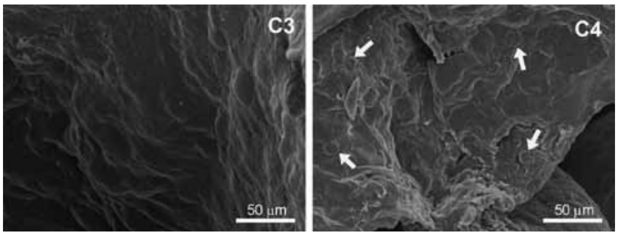

Figure 5. Cryo-SEM micrographs of cakes C3 and C4 (arrows: starch granules)

a lubricant and created a continuous and flexible structure. During baking, the oil globules released fat, which created a film that coated and smoothened the surface, as shown in Figure 5.

In comparison, the microstructure of C4 was irregular and with less integrity. Inulin could absorb part of the water creating competition for water with other ingredients such as gluten or starch. C4 was basically a protein structure in which gluten had difficulties in hydrating which affected its development into a continuous network. In addition, some starch granules were not fully incorporated into the matrix. So, in Figure 5, starch granules are identifiable as separate structures on the surface of the sample.

CONCLUSIONS

Oil increased the batter viscosity and helped to retain small air bubbles as observed in the interface air-matrix. During baking, oil was distributed as a coating layer linking the components and enabling the development of a homogeneous cell crumb structure. The leavening agent contributed to the optimal expansion of the structure in terms of height and sponginess. Inulin imparted less viscosity to the batter than oil. Bigger air bubbles were occluded, giving rise to a cake with an aerated structure and soft texture.

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