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Rheological and textural properties in a bakery product as a function of the proportions of the egg yolk fractions: Discussion and modelling

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With the aim of widening our knowledge about the structural changes induced by the components of egg yolk granules and their relevance in baked goods, rheological and other physical parameters have been studied in a real food system and correlated with the proportion of plasma/granules added in each case.

For this purpose, the whole egg yolk content was progressively substituted by its high protein-content granular fraction in a muffin recipe until a 100% granular recipe was obtained. Five different formulas, corresponding to different plasma/granules ratios, were used and another formula with 100% granules and containing mono- and diglycerides of fatty acids (E471) was tested too.

Flow curves at 25 °C and mechanical spectra at 90 °C were obtained for each substitution in order to evaluate the effect of the granules on the structure of the batter. In addition, other physical parameters of the baked muffins, such as hardness, were determined. The effects of the granular fraction on the aeration of the batter and on the baked muffins were also assessed by means of image analysis.

The progressive addition of granular proteins resulted in a non-linear increase in the consistency coefficient, the strength of the interactions and the hardness of the baked muffins, particularly from a plasma/granules ratio lower than 0.75. The addition of emulsifiers reverted the effects observed. These results suggest that the desirable effects of the egg yolk on the textural properties and shape of the muffin are due mainly to the effect of the plasma fraction.

1. Introduction

Egg yolk is a key ingredient in many food products, such as, for example, in sweet bakery formulations. These bakery products have a high fat content, which requires the addition of ingredients that act as emulsifiers, this being one of the main characteristics of egg yolk (Mine, 2002). Another functional property of egg yolk is the ability of its proteins to coagulate and thus form gels that may affect the texture and other qualities of cakes (Paraskevopoulou & Kiosseoglou, 1997). Furthermore, the influence of egg yolk on other cake parameters such as colour, flavour and appearance is well known.

Egg yolk can be easily separated into two fractions: plasma and granules (Laca, Paredes, & Díaz, 2010). The plasma fraction contains around 75–81% of egg yolk solids (Le Denmat, Anton, & Beaumal, 2000). It is composed mostly of low density lipoproteins (LDL) which are spherical particles with a core rich in triglycerides and cholesterol esters, and externally covered by a monofilm of phospholipids and apoproteins (Nakamura, Hayakawa, & Sato, 1977). In this fraction, the content in lipids and cholesterol is high.

On the other hand, the granular fraction contains mainly high density lipoproteins (HDL). These HDLs provide 70% of the granular content (McCully, Mok, & Common, 1962) and show a globular-like protein folding. Furthermore, these HDLs form a supramolecular structure with themselves and with phosvitin through phosphocalcic bridges, which can only be dissolved in media with high ionic strengths (>0.5 M NaCl) (Anton & Gandemer, 1997; Burley & Cook, 1961; Causeret, Matringe, & Lorient, 1991). These granular aggregates have a variable composition, forming different granule subclasses with different sedimentation behaviour (Strixner & Kulozik, 2013). Additionally, this fraction shows a high protein content and low levels of cholesterol, and it has functional properties that could allow its use as a whole egg yolk substitute in foods such as mayonnaises, having a cholesterol content-lowering effect (Laca, Sáenz, Paredes, & Díaz, 2010).

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It is also remarkable that these two fractions have a noticeably different microstructure and composition, resulting in different viscosity profiles at high temperatures (Ulrichs & Ternes, 2010) and consequently, their behaviour during the heating of egg-based products should be different too.

In previous research, the total substitution of the egg yolk by its granular fraction in a gluten-free muffin recipe was studied (Marcet, Paredes, & Díaz, 2015). However, how the different parameters vary with different plasma/granules ratios (P/G), and therefore to what extent these muffin parameters are affected by each sub-fraction remains unstudied. Hence, the aim of this work is to study, in a muffin recipe used as a model for an egg-based bakery product, the effect of different plasma/granules ratios on the structure of the batter and the baked product. Furthermore, the study of a muffin recipe made with only egg yolk granules and with food additives (E471) to reverse the effect of the egg yolk granules on the physical properties of the batter and of the muffins was also performed. Finally, the rheological and other physical parameters were modelled for a better understanding of the described phenomena.

2. Materials and methods

2.1. Obtaining egg yolk granules

Egg yolk and albumen were manually separated and the albumen residuals were eliminated from the yolk employing blotting paper (Laca, Sáenz, Paredes, & Díaz, 2010). Egg yolk material was mixed with water (1:1.5 v/v) and the pH of the diluted egg yolk was adjusted to 7 using NaOH (1 N). Then, it was kept overnight at 4 °C and centrifuged later at 10000 x g for 45 min to separate it into plasma and granules fractions.

2.2. Muffin preparation

The muffins were prepared and baked according to a traditional muffin recipe. The basic formulation includes 100 g of wheat flour containing 10.32% proteins and 1.2% lipids; 3 g of baking powder containing disodium diphosphate (E-450i), sodium bicarbonate (E-550ii), sodium carbonate (E-500i) and calcium sulphate (E-516); 65 g liquid pasteurized egg white; 35 g of fresh egg yolk; 100 g of refined sunflower oil and 100 g of sugar. All the ingredients were acquired from a local market.

Egg yolk and egg white were whipped for 3 min employing a 180 WATT hand blender (Morphy Richards HB01 Hand blender, UK) at maximum speed. Sugar and oil were added and mixed for 2.5 min with a 200 WATT mixer (Severin eletrogeräte, Germany), adjusting the speed control to level 3. Finally, flour and baking powder were added and mixed for 1.5 min using the same 200 WATT mixer. The batter was poured manually into the paper muffin cups, weighing out 38 g of batter each time. The muffins were always placed in the same place in a conventional oven, and baked for 24 min at 180 °C.

Table 1
Plasma/granules ratio (P/G) in each muffin recipe.

	P/G					
	3.5	1.6	0.75	0.3	0	0(+E471)
Egg yolk % (w/w)[a]	100	75	50	25	X	X
Granules % (w/w)[a]	X	25	50	75	100	100
Emulsifier E471% (w/w)[b]	X	X	X	X	X	2.5

[a] Percentage referring to the egg yolk content in the original recipe.
[b] Percentage of emulsifier with respect to flour.

Six different formulas of muffins were then prepared. As shown in Table 1, in each muffin the whole egg yolk (35 g) was progressively substituted by the granular fraction, which produces different plasma/granules ratios (P/G). Furthermore, in preparation P/G 0(+E471), 2.5% (w/w flour) of the emulsifier E471 (mono- and diglycerides of fatty acids) were added. The amount of emulsifier was previously tested at 0.5%, 1.5% and 2.5% (w/w flour), obtaining the best performance at 2.5% (data not shown). This emulsifier is a food grade additive and it is used in the industry to improve the mixing of the ingredients and the sponginess of the bakery products.

2.3. Specific gravity (SG) and image analysis of the batter

The specific gravity of each sample was calculated in duplicate as follows. A standard container was filled with batter and its weight was recorded and divided by the weight of the same container filled with water. Regarding the image analysis of the batter, a method similar to that of Gómez, Ruiz, and Oliete (2011) was carried out. An amount of fresh batter was placed on a microscope slide and a cover slip was used to create a thin layer of preparation. To maintain the same thickness in each case, two paperclips were used between the slips. The micrographs of the batters were obtained using an Olympus BX50 light microscope with 10× magnification. The number of bubbles was calculated in a surface of 4 mm^2 of raw batter using the ImageJ software. Furthermore, bubbles were distributed in three groups according to their size.

2.4. Rheological properties of batter mixes

Batters were kept for 60 min at 25 °C before the rheological test. Rheological properties of batters were determined with a Haake MARS II rotational rheometer using a Peltier unit to control the temperature. A plate/plate measuring system (PP60) was used with a gap of 1 mm where samples were left for 25 min to relax stress and stabilize the temperature. The excess of sample was removed, and a glass hood and silicone oil were employed to protect against dehydration during the experiment. Rheological measures were calculated in duplicate for two different batches.

2.4.1. Flow properties

Flow properties were measured at 25 °C. Apparent viscosity was obtained as a function of shear rate from 0.01 1/s to 100.0 1/s. The experimental time was adjusted to 300 sec. 100 points were collected with a logarithmic distribution and two flow curves of different batches of every formulation were obtained. Duplicates presented differences lower than 10%. Data obtained were adjusted to the Ostwald model (Martinez-Cervera, Salvador, Muguerza, Moulay, & Fiszman, 2011)

$$\eta = K\dot{\gamma}^{n-1} \quad (1)$$

Where η is the apparent viscosity, $\dot{\gamma}$ is the shear rate, K ($Pa.s^n$) is the consistency coefficient, and n is the flow behaviour index.

2.4.2. Dynamic tests

Frequency dependence tests were conducted at 90 °C in the range of linear viscoelasticity. The frequency range tested was from 10.0 Hz to 0.01 Hz. The experimental data obtained were adjusted to the following power law equation according to Gabriele, de Cindio, and D'Antona (2001).