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Rheological study of layer cake batters made with soybean protein isolate and different starch sources

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ABSTRACT

The study of new gluten-free foods suitable for celiac people is necessary since people allergic to wheat proteins are more and more frequent. This study examined the effect of using different starch sources (rice, corn, potato and wheat) and protein types (soy protein isolate, wheat protein) at different percentages (0%, 10%, 20%), on the rheological properties of batters (flow, viscoelastic and stickiness behaviour) and on batter density and cake volume. The highest consistency, viscous and elastic moduli, and adhesive force corresponded to batters made of rice starch and soy protein isolate, which showed the most similar rheological behaviour to wheat flour batters. The batters obtained showed adequate characteristics in processing and in achieving high quality products. However, the percentages of starches and proteins should be experimentally optimized in each case.

1. Introduction

Understanding the rheological characteristics of food materials is necessary in designing new products. It is important to determine the rheological properties of cake batters due to their effect on cake processing (Hoseney and Smewing, 1999) and on cake final characteristics (Sahin, 2007).

Cake batter can be considered as a complex oil-in-water emulsion with a continuous aqueous phase containing dissolved or suspended dry ingredients. The incorporation of air cells in the system during mixing gives rise to foam. A large number of small cells provide high cake volume if the continuous phase of the batter is capable of retaining them during the baking process (Gomez et al., 2007). The air incorporation depends on the speed and the design of the beater, and the viscosity and the surface tension of the batter. The efficiency of the air retention, however, is known to be inversely proportional to bubbles size and to the viscosity of the batter (Sahi and Alava, 2003). In fact there is an optimum cake batter viscosity to achieve cakes with high volume: if the viscosity of the batters is too low, batter cannot hold the air bubbles inside and cakes collapse in the oven. On the contrary, a too highly viscous batter can restrict its expansion during baking (Sahi and Alava, 2003). The optimum viscosity value also depends on the specific recipe. During baking, the aerated emulsion is converted to a porous semisolid mainly due to starch gelatinization and protein coagulation. Both these phase transitions are clearly dependent on the starch and protein sources (Roos, 1995). When an increase in starch gelatinization and protein coagulation temperatures takes place, the change of batter from a fluid, aerated emulsion, to a solid, porous structure, happens later, allowing the cake to increase its volume for a longer time (Stauffer, 1990).

Recently, there has been an increasing interest in gluten-free (GF) baking products, suitable for celiac people that necessarily have to adhere to a GF diet throughout their life. GF products are frequently produced with the addition of various proteins to a starchy base, to increase their nutritional value. The incorporation of dairy proteins has been long established in the bakery industry, but legumes, such as soybean, can be also a good supplement for cereal based foods. Soybean is an important legume because of their desirable functionality, high nutritional value and healthy properties (Ranhorta et al., 1975; Gupta, 1987; Hasler, 1998; Ribotta et al., 2004; Wilson et al., 2007). The addition of different starch sources to GF products such as corn, potato, wheat or rice (Gallagher et al., 2004; Gallagher, 2008; Ronda et al., 2009; Demirkesen et al., 2010) has been also analyzed. These studies are generally focused on bread preparation, and consequently they study the addition of hydrocolloids and gums to retain the gas incorporated during mixing. Few literatures can be found about yellow layer cakes so far, and the combination effect of soybean and different starch sources in batters and cakes should be considered.

The present work was focused on the study of the effect of the starch source and soy protein isolate at different percentages, on the rheology—including stickiness—of yellow layer cake batters

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and on the volume of the baking products prepared from them. Wheat protein addition was also studied in order to obtain information about the effect of the protein source.

2. Materials and methods

2.1. Materials

Corn starch (12.1% moisture), potato starch (17.2% moisture) and wheat starch (13.1% moisture) were obtained from Cargill (Mechelem, Belgium); rice starch (11.7% moisture) from Remy Industries NV (Leuven, Belgium); soybean protein isolate (SPI) (Prolisse 500, dry matter of 94.7% and protein content of 92.1% in dry basis) from Cargill (Mechelem, Belgium) and wheat protein (WP) (gluten vital, dry matter of 91.0% and protein content of 75% in dry basis) from Huici Leidan S.A. (Navarra, Spain). Wheat flour (moisture 14.5%, protein 10.2% in dry basis and ash 0.55% in dry basis) was supplied by Harinera Castellana (Medina del Campo, Spain). Sugar, milk, whole eggs, sunflower oil and baking powder were bought in local shops.

2.2. Batter and cake preparation

The formula, based on the mixture starch–protein weight, was: 120% sugar, 60% milk, 50% whole egg, 30% sunflower oil, and 3% baking powder. The starch–protein stock mixtures were previously prepared. Four starch sources and two different protein types were tested. Three different contents of protein in the mixture were studied: 0%–10% and 20%. The experimental design was then a $4 \times 2 \times 3$ factorial. A single-bowl mixing procedure was used to prepare the batter. All ingredients were mixed during 10 min, at speed 4 during 1 min and at speed 6 during 9 min, using a Kitchen–Aid Professional mixer (KPM5). The same procedure than in previous work (Ronda et al., 2009) was used to prepare the yellow layer cakes from the ingredients. Each formulation was prepared and measured in duplicate.

2.3. Batter properties

2.3.1. Flow behaviour

Flow tests were carried out at 25 °C with a Brookfield DVII+viscosimeter provided with a small size sample adaptor, SC4-28. Results were fitted to the power law: $\tau = K \cdot \dot{\gamma}^n$, where K is the consistency index (Pa s^n), n is the flow behaviour index, τ is the shear stress (Pa) and $\dot{\gamma}$ is the shear rate (1/s). Besides the mixtures starch–protein studied, wheat flour was also analyzed in order to compare results.

2.3.2. Viscoelastic behaviour

Dynamic test were carried out with a Rheostress 1 rheometer (Thermo Haake, Karlsruhe, Germany) with parallel plate geometry (60 mm diameter) of serrated surface and with 1 mm gap. The excess of batter was removed and vaseline oil was applied to cover the exposed sample surfaces. Before the measurement, the batter was rested for 5 min to allow relaxation. Frequency sweeps were carried out from 10 to 0.1 Hz and always were conducted in the linear viscoelastic zone previously established for each batter by means of stress sweeps from 0.1 to 100 Pa. The limit of the linear viscoelastic zone was located for all the batter tested in the range 0.5–2 Pa and the measurements were carried out at a constant value of 0.4 Pa. Temperature was 25 °C. Frequency sweep data were fitted to the power law model (Sivaramakrishnan et al., 2004):

$$G'(\omega) = G'_{\omega 1} \cdot \omega^a$$

$$G''(\omega) = G''_{\omega 1} \cdot \omega^b$$

$$\tan\delta(\omega) = \frac{G''(\omega)}{G'(\omega)} = \left(\frac{G''}{G'}\right)_{\omega 1} \cdot \omega^c = (\tan\delta)_{\omega 1} \cdot \omega^c$$

The coefficients $G'_{\omega 1}$, $G''_{\omega 1}$, and $(\tan\delta)_{\omega 1}$, represent the elastic and viscous moduli and the loss tangent at a frequency of 1 Hz. The a, b and c exponents quantify the dependence degree of these moduli and the loss tangent with the oscillation frequency. Besides the mixtures starch–protein studied, wheat flour was also analyzed in order to compare results.

2.3.3. Stickiness

This assay was conducted by following the procedure proposed by (Grausgruber et al., 2003). A texturometer TA-XT2 from Stable Microsystem (Surrey, UK) provided with a SMS/Chen-Hoseney device where the sample was placed, and a methacrylate 25 mm cylinder (P/25P) as compression cell, were used. Three parameters were used to define stickiness: the positive maximum force or adhesive force, which is the measure of stickiness, the positive area under the curve or the adhesive energy, which is the work of adhesion, and the distance the sample is extended on probe return, which is an indication of sample cohesion/dough strength. Six replicates were carried out for all batters.

2.3.4. Batter density

Batter density was determined in duplicate with a measuring cylinder by means of the relation between the weight of batter and the same volume of distilled water.

2.4. Cake volume

Cake volume was determined in quadruplicate using a volume analyzer BVM-L370 (TexVol Instruments,Viken, Sweden).

2.5. Statistical analyses

In order to assess the effect of the studied factors—starch source, and protein type and concentration—on the batter and cakes properties, a multiple comparison analysis of samples using the program Statistica V6 (Tulsa, OK, USA) was applied. Fisher's least significant differences (LSD) test was used to describe means with 95% confidence.

The correlation study between variables was carried out with the software Statgraphics Plus V5.1 (Bitstream, Cambridge, M.A, USA). The Pearson coefficients, which can go from −1 to +1, are shown as a measure of the strength of the linear relationships between the pairs of variables studied. The number of data used to study each correlation was always 20.

3. Results and discussion

3.1. Batter flow behaviour

Experimental data provided a good fit ($r^2 > 0.99$) for the power law model (Table 1). The consistency (K) and flow behaviour (n) for the different batter formulations are given in Table 1. The flow behaviour index ranged from 0.67 to 0.81. So, all the formulations showed a shear thinning (pseudoplastic) behaviour, which means that the apparent viscosity decreases as the shear rate increases. All the batter types were found to have a slight thixotropic behaviour. Fig. 1 shows the flow curves of some cake batters obtained in shear rate cycles (up-down). As the "down-curves" are below the "up-curves" (measured first), it can be concluded that the apparent viscosity decreased with time for a constant share rate. The same behaviour was observed by other authors in wheat–corn flour