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Development of Bakery Formulation for Sprayable Cake Preparation

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The aim of this work was to create an innovative sprayable bakery mix for foam-style cake preparation. The main goal was to obtain a batter liquid enough to be easily and quickly dosed in a spray system but maintaining its structure during baking. A commercial liquid batter was selected, and its recipe modified to fit in a spray system. The commercial bakery mix was characterized in terms of physical-chemical, thermal, and rheological attributes. The product was then diluted with milk or whipping cream at a 3:1 ($g_{product}/g_{diluent}$) ratio to modulate its viscosity to be sprayed in a nitrous oxide loaded siphon system. All the prepared samples were characterized in terms of physicochemical properties at different stages of cake production (before and after spraying, and after baking) to investigate the effect of dilution on rheology and spray-ability and on the texture of final cake. Before cooking, the dilution determined an increase of water content and activity and a remarkable difference in colour coordinates compared to the reference. However, the differences in physicochemical parameters were minimized after baking due to water content reduction and non-enzymatic browning phenomena. Despite that, the diluent type affected thermal characteristic peaks linked to fat melting and starch gelatinization phenomena, respectively. In fat melting, whipping cream addition maintained enthalpy values similar to control due to the high lipid content balancing the dilution effect. Instead, the greatest water amount in milk contributed to fat reduction and enthalpy reduction. In starch gelatinization, both milk and cream addition determined a reduction of the associated total energy due to a starch dilution effect. From a rheological point of view, a significant decrease in viscosity enabled the diluted batter to be sprayed. All samples displayed shear rate dependent and shear-thinning behaviour. When the batter was sprayed the values of apparent viscosity suddenly increased, probably due to a reduced droplet size, minor average inter-particle distance and the interaction of foaming agents and proteins. After baking, sprayed samples showed firmness and springiness comparable to the control cake. However, the cakes from both the diluted batters presented some cooking defects typical of an incorrect leavening process enforced by yeast dilution and lack in aeration stability during baking.

1. Introduction

Cakes are one of the most consumed bakery products because of their delicious spongy texture and organoleptic and sensorial characteristics (Rodríguez-García et al., 2013). The physicochemical properties of cakes are largely dependent on the batter and cake structure. Cake batters are complex emulsions of fat or oil in an aqueous phase, containing flour (Lee, 2015; Aydogdu et al., 2018), eggs (Hedayati & Tehrani, 2018), sugar (Cavalcante & Mendes da Silva, 2015), and minor ingredients. The quality of high air-leavened products such as sponge cakes, cupcakes or muffin depends on many factors, including the ingredients used for batter preparation, aeration of batters, and processing conditions to guarantee the typical soft and fluffy texture (Chaiya & Pongsawatmanit, 2011). Among the ingredients, fats not only contribute to the sensorial in-mouth experience but they play a primary role as crumb structurer and stabilizer by entrapping air bubbles formed during leaving and cake expansion (Matsakidou et al., 2010) Egg has several binding, emulsifying and foaming functional properties (Wilderjans et al., 2013) Especially in foam-style cakes, the foam formation is provided by eggs in conjunction with other ingredients, such as sugar and acid, in order to delay gluten formation and air bubble production (Cavalcante & Mendes da Silva, 2015). Mixing mechanism is also crucial for preventing the wheat network and to enhance potential foam formation by eggs (Rodríguez-García, et al., 2014). During cake batter mixing, the movement of the mixing tool pushes materials aside, creating a void in

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which the batter flows and small pockets of gases are entrained decreasing the density of batter. Low batter density is associated with good air incorporation and good bubble retention during mixing. On the other hand, during baking the batter viscosity controls air and leavening gas retention, that is important to guarantee the creation of a stable sponge structure that will not collapse after baking (Sahi & Alava, 2003). Assuring correct level of overrun in a liquid phase is the most critical factor in cake manufacturing and failing to do so could lead to several problems in final product standardization. A possible solution is to develop a mix in which air or gases are already incorporated into to the system during dosing. Sprayable formulation can modulate the right number of bubbles inside the structure providing the right elasticity and fluffiness of the bakery product.
Some sprayable solutions already exist for pancakes (Batter Blaster, USA) and on 2014 a start-up (Spray Cake, USA) developed an idea to manufacture a sprayable cake batter, even if more recent updates were not found. The idea of sprayable cake is to create a ready-to-bake product easy to dose and quick to prepare, using a siphon loaded with pressurized gases (nitrous oxide or carbon dioxide) to spray the product and bake it in the oven or in the microwave (Lostie et al., 2002a, 2002b). During spraying, the batter-gas mix is expelled from the siphon, the gas quickly expands due to the pressure difference between the inside of the siphon and the outside at atmospheric pressure, making the product obtain a consistency like whipped cream. However, the main limitation is that cake batters possess a very high viscosity. Therefore, to spray them, the product must be diluted with suitable ingredients (e.g., dairy products such as milk or fresh whipping cream) that contain foaming agents that can drop the bulk density and promote air formation (Blankart et al., 2020; Green et al., 2013). The aim of this research was then to develop an innovative ready-to-bake product suitable to be sprayed. A commercial liquid batter was selected and opportunely diluted with milk or whipping cream at a 3:1 ($g_{product}/g_{diluent}$) ratio in recipe to reduce the viscosity and to be used in a nitrous oxide loaded siphon system.

2. Materials and Methods

2.1 Materials

Commercial refrigerated liquid batters for cakes (Soffice Margherita, Cameo), whole milk (Coop), and fresh cream for dessert (Centrale del latte) were purchased from local market. A cross-nozzle stainless-steel siphon (Upstartech, USA) was used as spray system loading nitrous oxide cartridge at 8.9 atm.

2.2 Sample preparation

Liquid commercial batter was selected as a control reference. 150 g of cake mix were diluted adding 50 g of milk or fresh whipping cream at a 3:1 ($g_{product/}g_{diluent}$) ratio according to preliminary tests. The batter was then homogenized for four minutes in a lab scale planetary mixer (Imetec Zero Glu, Italy). After mixing, the batter was scraped out from the walls and the bottom of the bowl to recover all the material and to obtain the samples before spraying (t0). Subsequently, the liquid was poured into a nitrous oxide-loaded siphon and sprayed to obtain the final batter (t1). The mixture was shaken for 10 seconds before use. All samples (control, t0 and t1 batters) were baked in a semi-industrial oven Wind+ 6040/5 (Polin, Italy) for 30 minutes at 165°C using aluminum (20x30cm) vessels. Three replicates were performed for each sample.

2.3 Sample Characterization

Moisture Content, aw, pH and Color

The moisture content was determined as weight loss of samples (5 g) after 24 h in an oven at 105 °C. The pH was measured using a pH meter (Hanna instruments, Italy) equipped with a Bluetooth probe system. The probe was inserted inside the batter and the pH value was recorded. Demineralized water was used to clean the probe after usage. Water activity (aw) was measured using an aw analyzer (AcquaLab, Astori tecnica, Italy). The sample was placed in a plastic cup filling half of its volume and then allocated into the instrument chamber to perform the measurement at a constant temperature of 25 °C. Color was measured using a colorimeter (Hunter lab D25 NC, USA). Sample was placed in plastic Petry dish and measured in different point. Trichromatic coordinates L*, a* and b* and color change or ΔE value ($\sqrt{\Delta a^{*2} + \Delta b^{*2} + \Delta L^{*2}}$) after baking were obtained. All the analyses were performed in triplicates (five replicates for color analysis).

Rotational Rheology

Rotational measurements were carried out using a controlled-stress rheometer (MCR 302, Anton Paar, Austria) provided by cup and bob device. A sample volume of 25 mL was poured into a 27 mm cup and bob attachment (cell height 40 mm, annular diameters 26.65 and 28.92 mm). Measurements were performed at 25 °C ± 0.1. The shear rate was set between 0.01-100 s^{-1}. Samples were loaded into the cell and exposed to pre-shear of 10 s^{-1} for 10 s followed by 10 s rest according to the method by Taylor et al. (2009). All the measurements were carried out in triplicates.

Differential Scanning Calorimetry

A microcalorimeter (Setaram, France) equipped with a 3D Calvet sensor was used to perform the analysis. The sample (0.5 g) was weighed in Hastelloy cells. The following thermal ramp was selected according to previous studies (Rodríguez-García et al., 2014; Turabi et al., 2010) with slight modification. The sample was hold at 20°C for 10 minutes. Then, temperature was increased up to 160°C at 0.8°C/min rate. Finally, after 5 min holding at 160°C, a cooling ramp was set to reach 50°C at 1°C/min rate. All tests were carried out in duplicates.

Texture Profile Analysis (TPA)

TPA analysis of final cakes in double compression was performed one hour after baking, with a Texture Analyzer TVT 6700 (Perten, Sweden). A 75 mm cylindrical probe was used to compress the sample up to 30% of the initial volume. The test speed was set at 2 mm/s. A holding time of 15 s was selected between the first and the second compression. Each sample was cut in rectangular 3x3 cm pieces with 1.5 cm height. According to Salehi and Kashanine (2018) method, the upper crust was removed in order not to bias the measurements. Firmness and springiness attributes were computed by instrument software. Measurements were carried out at 25 °C ± 0.1 and with five replicates for each sample.

Statistical analysis

Results are reported as mean values of the replicates with their corresponding standard deviations. The influence of leavening agent on characteristics of doughs and cakes was evaluated through one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test for means discrimination, at $p \leq 0.05$ level, using statistical software SPSS® (version 21.0, SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

Moisture Content, aw, pH and Color

The main results are resumed in Tab 1. All diluted samples show higher water activity and moisture content compared to the reference both before (0.92<aw<0.94, 34.64<moisture%<42.86) and after baking (0.84<aw<0.90, 25.49<moisture%<36.68). The greatest values were detected for milk dilution due its higher water content compared to whipping cream. Moreover, the commercial product already possesses a high water activity (0.85), and a further increase could cause a negative effect on stability and decrease the product shelf-life (Podolak et al., 2010). However, after baking a decrease was observed in both parameters for all samples. Contrarily, all sprayable cakes exhibited the highest moisture content, that could improve the sensorial score of final products in terms of firmness and elasticity (Chuang & Yen, 2006). Furthermore, the dilution with both milk and cream led to change in color for batter from an intense yellow to a lighter color. This fact was shown by the increase in L* that further increased after spraying. The change of all trichromatic coordinates at t1 seemed to indicate an effect related to the incorporation of air into the batter. The baking process lowered the L* and b* values and increased a*. The latter result is correlated to the browning phenomena induced by Maillard reactions during cooking. Among all, milk samples exhibited darker color (expressed by higher ΔE), probably due to the higher amount of lactose that promotes browning (Table 1).

Rotational and Oscillatory Rheology

Figure 1 shows the curves of the apparent viscosity at 25°C versus the shear rate for control and batters at different conditions of dilution before and after spaying. All samples display shear rate dependency and shear-thinning behaviour. As shown in Figure1a, after dilution, samples exhibit lower apparent viscosities compared to the reference. When the batter is sprayed, the values of apparent viscosity suddenly increase due to a reduction in droplet size, a minor mean interparticle distance and a greater interaction by foaming agents and proteins (Zhao, et al., 2013; Lim, et al., 2008). An inverse relationship between viscosity and fat droplet size in whipped system was reported by Chanamai & McClements (2000). Same results were found in more recent study performed by Zaho et al. (2012) using high pressure homogenization (HPH): increasing HPH pressure determines a higher interparticle resistance. In addition, the reduction of droplet size enhances the amount of the adsorbed protein fraction resulting in higher apparent viscosity. Amiri et al. (2018) confirmed the latter result for sonicated whipped cream: sonication decreases the particle size distribution of fat globules, losing the grapelike structures observed in untreated samples and causing a limited opening of protein chains and the formation of new bonds to cover the fat cells, and the resulting interactions can somewhat increase viscosity. Finally, sprayed samples show a rapid drop of viscosity at high values of shear rate compared to diluted batters, underlining the greater instability of whipped systems.

Table 1: Evaluation of the water activity, moisture and colour difference ΔE of the analysed samples. The values are expressed as mean value± d.s. Different letters within each column indicate significant differences between the samples (ANOVA and Tukey's post-hoc test with α <0.05).

Sample	Before Baking			After Baking		
	aw [-]	Moisture [%]	ΔE [-]	aw [-]	Moisture [%]	ΔE [-]
Control	0.855 ± 0.006[a]	26.02 ± 0.34[a]	0.0	0.746 ± 0.021[a]	22.21 ± 0.26[a]	0.0
t0 cream	0.921 ± 0.004[b]	34.92 ± 1.69[b]	11.0	0.839 ± 0.008[b]	25.49 ± 0.99[b]	1.5
t1 cream	0.924 ± 0.004[b]	34.64 ± 1.08[b]	46.7	0.841 ± 0.006[b]	26.63 ± 0.30[b]	2.5
t0 milk	0.943 ± 0.001[c]	40.95 ± 0.10[c]	40.1	0.896 ± 0.004[c]	34.39 ± 1.03[c]	10.5
t1 milk	0.944 ± 0.004[c]	42.86 ± 0.07[c]	47.1	0.903 ± 0.001[c]	36.68 ± 0.40[d]	9.0

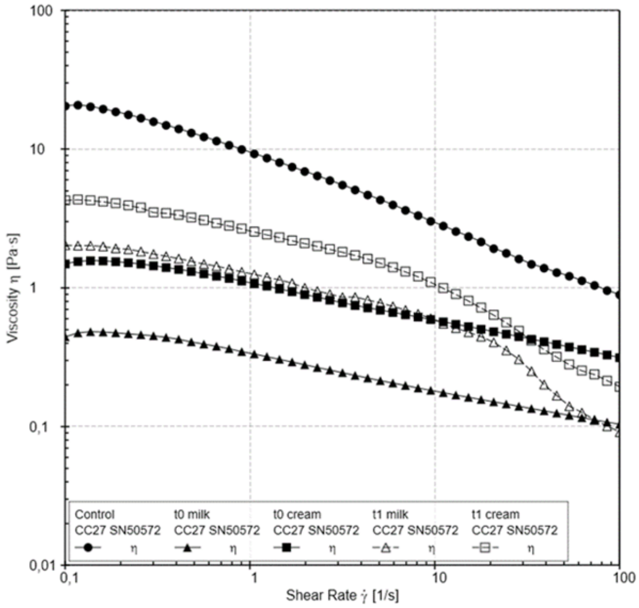

*Figure 1: Flow curves of samples: apparent viscosity (Pa*s) as function of shear rate (s^{-1}) at 25°C obtained for the control (black circle), after dilution(t0) with cream (black squared) and milk (black triangles), and sprayed milk (white triangles) and cream (white squared) (t1) batter.*

Differential Scanning Calorimetry

Before baking, all t0 batters show thermograms like the reference. Two characteristic endothermic peaks at 60°C and 80-90°C are detected. The enthalpy (ΔH) and the onset (Ton), peak (Tp) and offset (Toff) temperature of each peak are reported in Table 2. According to Truong et al. (2018), the peak obtained at 60°C corresponds to the melting of fats. In fat melting, cream batter maintains its enthalpy value like the control due to its high lipid content that balances the dilution effect. Instead, the greatest water amount in milk contributes to fat reduction and lower energy. The second encountered peak is related to starch gelatinization phenomena as obtained from previous studies (Rodríguez-García et al., 2014; Turabi et al., 2010). Milk and cream addition determine the onset of phenomenon at lower temperatures. Moreover, enthalpies involved are smaller than the control confirming a reduction of the starch content due to dilution.

Texture Profile Analysis (TPA)

Low deformation (up to 50%) tests are suitable to assess the texture attributes of elastic bakery product such as bread and cake (Hesso et al., 2015). In a double compression TPA analysis “firmness” is defined as the force required to reduce the sample volume in the first and second compression, respectively. Once those two data were obtained, "springiness" is calculated as the ratio between firmness values. Springiness is an index related to the elasticity of the sample (Hesso et al., 2015). In particular, if the values of firmness in first and second compression are similar, the sample will be highly elastic. In Figure 2a firmness values are reported comparing the baked diluted sample before (t0) and after spraying (t1) to the control sample. Batters with the only addition of cream and milk (t0) are significantly higher than the control. Especially t0 milk-diluted samples exhibit a value of hardness four times greater than the control. However, sprayed samples (t1 milk and t1 cream) show firmness comparable to the not diluted batter. No significant differences are detected in elasticity neither due to the dilution effect or to spraying. Nevertheless, Figure 2b reports the pictures of internal crumb of all sample after baking. It can be noticed that both t0 and t1 samples present some cooking defects which typically appear when the leavening has not taken place correctly. This result might be since addition of cream or milk decreased the concentration of yeast of the original formulation. Moreover, it is possible that the spraying action does not improve softness because the structure is not able to keep the added air during baking. In any case, a further optimization of formulation by thickeners addition or increasing yeast concentration should avoid leavening problems, enhancing final structure quality.

Table 3: Evaluation of the characteristic endothermic peaks of fat melting and starch gelatinization obtained by DSC analysis for batters before baking. The values are expressed as mean ± d.s. Different letters within each column indicate significant differences between the samples (ANOVA and Tukey's p post-hoc test with α <0.05).

Sample	Fat melting				Starch Gelatinization			
	Heat (J/g)	Ton (°C)	Tp (°C)	Toff (°C)	Heat (J/g)	ton (°C)	Tp (°C)	Toff (°C)
Control	0.434 ± 0.03^{a}	57.2 ± 0.48^{a}	59.4 ± 0.14^{a}	61.9 ± 1.16^{a}	2.54±0.04^{c}	87.14±1.97^{b}	93.80±0.08^{c}	97.74±6.25^{a}
t0 milk	0.333 ± 0.02^{b}	58.4 ± 0.66^{a}	59.7 ± 0.44^{a}	61.2 ± 0.11^{a}	1.74±0.00^{a}	74.78±0.12^{a}	79.73±0.07^{a}	84.63±0.09^{a}
t0 cream	0.434 ± 0.01^{a}	57.9 ± 0.16^{a}	59.9± 0.53^{a}	62.2 ± 1.07^{a}	1.92±0.02^{b}	83.97±0.19^{b}	89.52±0.22^{b}	95.00±0.42^{a}

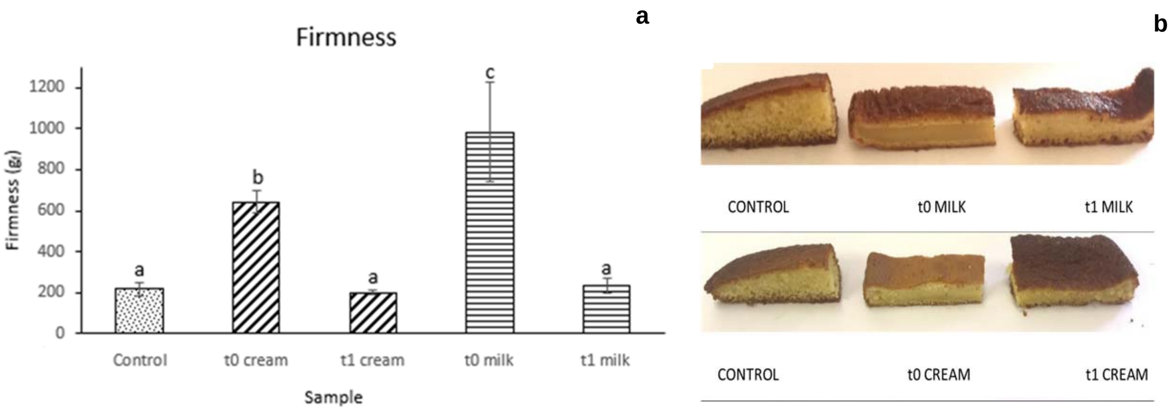

Figure 2: a) Evaluation of the firmness expressed in force grams (gf) of the analysed baked samples. The values are expressed as mean ± d.s. Different letters indicate significant differences between the samples (ANOVA and Tukey post-hoc test with α <0.05). b) Pictures of internal crumb of cake samples obtained from control, t0 and t1 diluted batters and baked at 165°C for 30 min.

4. Conclusions

The aim of this work was to create a sprayable bakery mix for foam-style cake preparation diluting a commercial liquid batter with milk or whipping cream at a 3:1 ($g_{product}/g_{diluent}$) ratio, to be dispensed in a spray system. Before cooking, dilution mostly determines an increase in water content and water activity that can affect shelf-life but also increase the sensorial score of final products. Diluent type affects also thermal characteristic peaks linked to fat melting and starch gelatinization phenomena. From a rheological point of view, a significant decrease in viscosity enables the diluted batter to be sprayed at the selected ratio. All samples displayed shear rate dependency and shear-thinning behavior. However, when batters are sprayed, the values of apparent viscosity suddenly increase due to a reduction of the droplet size, a minor average interparticle distance and a possible interaction of foaming agents and proteins. After baking, sprayed samples (t1 milk and t1 cream) show firmness and springiness comparable to the reference. Although, both t0 and t1 cakes present some cooking defects typical of an incorrect leavening process, enforced by yeast dilution and lack in aeration stability during baking: a further optimization of the formulation by adding thickeners or increasing yeast concentration should avoid leavening problems, enhancing final structure quality.

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