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The predictive power of batter rheological properties on cake quality - the effect of pregelatinized flour, leavening acid type and mixing time

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Abstract

Rheology of cake batter is considered an important parameter determining cake quality. It is thus frequently used to investigate structural changes in the process of cake making. However, little is known about the relation between batter rheological properties and cake's final properties, concerning volume and texture. In order to explore this relation an extensive experiment covering broad recipe variability was performed using an advanced experimental design approach and subsequent statistical analysis. The mixture of standard with pregelatinized wheat flour had significant main and interaction effects on most responses characterizing cake batter. Leavening acids and mixing time affected only a few of them. The simultaneous influence of ingredients and mixing time was clearly described. Measuring the batter rheological properties immediately after mixing gave sufficient information to significantly estimate in advance the volume of the cakes together with their cohesiveness. This methodology could improve the design of new bakery products with desirable volume and texture.

Keywords: cake ingredients; mixing time; rheology; texture

1. Introduction

Globally, millions tons of baked goods are sold each year. The worldwide growth of baked goods remains positive due to the growing market of Asia –Pacific and the positive growth rate of the submarket of cakes and pastries. The demand for cake is being driven by indulgence and flavor innovation, with affordability remaining a key concern. Although cake is an important baked product, research concerning cake is scarce and there is a lack of understanding of the mechanisms during cake making. Because many different types of cake exist, the research area is rather broad (Wilderjans et al., 2013). This paper discusses batter type cake, more specifically high fat cake, which is composed of wheat flour, whole egg, fat and sugar.

Each ingredient used in the batter and each step in the cake making process potentially has an impact on the properties of the final product. Batter ingredients and mixing process parameters determine the rheological properties of the batter (Meza et al., 2011, Chesterton et al., 2013).

Rheological properties of cake batter have been determined for the evaluation of a dosing process (Baixauli et al., 2007), for verifying the adequacy of wholegrain flours from rye, triticale, barley and tritordeum as wheat flour replacers (Gomez et al., 2010), for testing the substitution of sucrose by sucralose and polydextrose (Martinez-Cervera et al., 2012, Schirmer et al., 2012), for studying the air incorporation by two different bench mixers and for testing the role of heat treated flour in cake making (Chesterton et al., 2013, Meza et al., 2011). In all cases, batter exhibits shear thinning behavior. Moreover, viscoelastic properties of batter have been investigated by dynamic oscillatory measurements indicating elastic behavior (Hesso et al., 2015a, Sanz et al., 2005) or viscous behavior (Meza et al., 2011, Ronda et al., 2011) depending on the batter formulation.

To simulate the structural changes in batter during baking, its viscoelastic properties have also been measured during a temperature ramp with constant strain (within the linear viscoelastic range) and frequency (often at 1 Hz) (Martinez-Cervera et al., 2012, Baixauli et al., 2007, Schirmer et al., 2012, Hesso et al., 2015a). The temperature at which the moduli start to increase, after an initial decrease, reflects the beginning of structure setting due to starch gelatinization and protein denaturation.

Among other properties, a soft texture is an essential parameter of cake quality. Texture Profile Analysis (TPA) has been widely used to simulate the process of biting and chewing in the mouth. Although TPA values obtained at compressions of extended deformations provide more information to explain sensory perception (Fizman et al., 2005), the cake texture assessment is mostly performed by low deformation (till 50 % strain) (Gomez et al., 2007, 2010, Wilderjans et al., 2010, Hesso et al., 2015a). Cake texture is related to both porous structure and mechanical properties of the solid phase, the cake matrix. Ingredients and processes during cake making influence cake texture. Improvement in softness of degassed cakes, and thus of the solid phase, have been associated with

substitution of wheat flour with pregelatinized starches (Hesso et al., 2015b). However, this positive impact of pregelatinized starch on cake texture was cancelled out by the denser structure of pregelatinized starch cakes (Hesso et al., 2014). In addition, cake porous structure is positively influenced by chemical leavening agents. The leavening agents, a mixture of bicarbonate with acids, release carbon dioxide gas into the batter through an acid-base reaction, creating the nuclei that expand during baking and creating the light texture of cake. Unleavened cake systems have dense structure (Lambert et al., 1992).

For designing new cake products with desirable structural and texture characteristics, it is mandatory to understand the effect of the rheological properties of the batter on these properties. Edoura-Gaena et al. (2007) found a significant correlation between the flow properties of batter and the texture properties of biscuit. Hesso et al. (2015a) studied the effect of batter formulation on viscoelastic batter properties and cake quality properties, then explained cake textural characteristics based on the localization of cake components in the cake microstructure. Even though batter rheological properties and cake texture have been studied separately for a variety of reasons, to the best of our knowledge, there are no studies quantitatively relating batter rheological properties, both flow and viscoelastic, to cake volume and texture. This relation would provide insight into the predictive power of batter rheological properties in final cake quality. In order to investigate such a relation, an appropriate experimental design is required to define a sufficiently wide range of cake formulations.

The choice of an experimental design depends on the objectives of the experiment, the number and the type of factors to be investigated. Response surface methodology, a statistical approach of which experimental design is a key component, has been widely used in cake and bread experiments to study quantitative factors. More specifically, central composite design has been used by Pizarro et al. (2013) to study the effects of an innovative type of flour (chia) on pound cake properties and a Box-Behnken design was used by Tan et al. (2012) to optimize the cake batter mixing conditions. However, when there is need to study experimental factors which are proportions of ingredients, central composite designs and Box-Behnken designs are no longer optimal, and mixture experimental designs are appropriate. Mixture experiments are more complicated than classical response surface experiments, because the proportions of the mixture under study must sum to one. In some cases, mixture experiments involve additional constraints on the individual ingredient proportions, as well as on linear combinations of the ingredient proportions. In addition, it is sometimes necessary to include one or more process variables in the mixture experiment. The optimal design of mixture experiments with process variables and the analysis of the resulting data are discussed in Goos and Jones (2011). An even more complicated experimental design is required when the ingredients of a mixture are mixtures themselves. The resulting experiment then is a mixture of mixtures experiment, in which a formulation is a mixture of two or more “major” ingredients, each of which is a mixture of one or more “minor” ingredients (Piepel, 1999).

The goal of this article is to gain a quantitative understanding of how the rheological properties of the batter affect the structural and textural properties of the cake. This will contribute to a more effective design of new products with desirable characteristics. In the study we present here, for the first time a mixture of mixtures experimental design involving an additional process variable, namely mixing time is used. The main cake ingredients, flour, sugar, margarine, egg and leavening agents represent the "major" ingredients of the design. Two types of flour and three types of leavening acids are the "minor" ingredients.

2. Materials and Methods

2.1. Batter, cake and sample preparation

Cake batter was prepared by the single stage method using wheat flour (Brabomills, Belgium), pregelatinized wheat flour (CERES, Soufflet group, Belgium) (the two flours were used in a mixture of 800 g in total), sugar (Tiense Suiker, Belgium) (800 g), pasteurized liquid egg (Cocovite, Belgium) (720 g), margarine (All Bak, Jan Gevers, Belgium) (520 g), sodium bicarbonate (NaHCO_3) (Brenntag, Belgium) (9.44 g), combinations of leavening acids (disodium pyrophosphate ($\text{H}_2\text{Na}_2\text{O}_7\text{P}_2$) (SAPP 10 and SAPP 28) and calcium phosphate monobasic monohydrate ($\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$) (MCP) (respectively with trade names: Levall AR 10 Levall AR 28 and Levall Ca100, Budenheim, Germany) and distilled water (176 g). The quantities of leavening acids were calculated by the neutralization value of sodium bicarbonate. The neutralization value (NV) is the parts by weight of baking soda from which all available carbon dioxide will be released by 100 parts by weight of a leavening acid: $\text{NV} = \text{g NaHCO}_3$ neutralized by 100 g acid. NV of MCP is 80, while for SAPP it is 73. Before mixing, margarine and egg temperature were adjusted to 20 °C by placing them in a water bath. All ingredients were mixed at the maximum speed of 675 rpm in a kitchen robot (Kenwood, type KMM020Major Titanium, Belgium). Three mixing times were used: 7, 10 and 13 min.

After mixing, 600 g batter was poured in each of 4 steel pans (24 cm x 9 cm x 6.5 cm), greased with oil spray (Pancoating spray, Jan Gevers, Belgium). The cakes were baked for 45 min at 175 °C in a convection oven (Four 46.4 A/VAP Krystal, Bongard, Strasbourg, France). At the same time with baking, batter density and batter rheological measurements were performed. After baking, the cakes were left in their pans to cool for 15 min, and then they were removed from the pans and placed on racks to cool for one hour. After cooling, the cakes were wrapped in plastic foil to prevent moisture loss. 24 h later, the cakes were weighed and their volume was measured by the rapeseed displacement method.

2.2. Experimental design

The experiment involved six factors: two flours, three leavening acids and mixing time. In total 30 cake recipes were studied. This number of recipes was divided into 10 blocks of 3 batches, because of labor constraints. So, each block of the experimental design corresponded to another day. The design had restrictions as follows: in the flour mixture, up to 30% of standard flour could be substituted by pregelatinized flour, according to results of preliminary experiments (results not shown), the maximum proportion of the fast leavening acid in the leavening acid mixture was 30%, according to results of preliminary experiments (results not shown), the proportions of moderate and slow leavening acids could range from 0% to 100%.

The experimental design was optimized for estimating a regression model involving the factors' main effects, the two-factor interactions, the three-factor interactions involving the mixing time and the quadratic effect of the mixing time (Goos and Jones, 2011). The model considered combines the models of Piepel (1999) and Kowalski et al. (2000). In order to be able to predict well with the regression model, we opted for an I – optimal experimental design, which minimizes the average prediction variance (Goos et. al., 2016). The software JMP 11 was used to create the design and to analyze the resulting experimental data.

2.3. Batter properties

Batter density was determined by using a 114 cm³ container of known mass (43 g) at room temperature. The cup was filled with batter, leveled on the surface using a spatula and weighed on an analytical balance. The *batter density* measurement was performed in triplicate for each batter prepared, immediately after preparation. The rheological properties of the batter were determined by rotational and oscillatory tests with a Physica rheometer MCR301 (Anton Paar Benelux BVBA, Belgium) equipped with a Peltier system to control the temperature and software Rheoplus/ 32. A 25 mm diameter plate - plate sensor geometry with a serrated surface and 1-mm gap between the plates was employed. To protect against dehydration during long measurement times, a solvent trap with cover was used. Batter rested in the measurement cell for 3 min before testing to allow stress relaxation and temperature equilibration. Simulating the effect of heating in the batter structure, a temperature sweep, from 20 to 95 °C at a frequency of 1 Hz, strain amplitude of 0.1 % and heating rate of 4 °C/min, was carried out immediately after mixing, simultaneously with the baking process. The maximum loss tangent ($Max\tan\delta$), the corresponding temperature ($T_{max\tan\delta}$) and the temperature at which minimum storage modulus (G') occurs (T_{minG}) were extracted from the curve as main parameters. The loss tangent is the ratio of viscous modulus (G'') to elastic modulus (G') ($\tan\delta = G''/G'$) and is a useful quantifier of the presence and extent of elasticity in a fluid. $\tan\delta$ values of less than unity indicate elastic-dominant (i.e., solid-like) behavior and values greater than unity indicate viscous-

dominant (i.e., liquid-like) behavior. In a typical temperature sweep, a decrease in both viscoelastic moduli is observed first, followed by an increase (Sanz et al., 2005, Baixauli et al., 2007). The decrease of $\tan\delta$ in the second part of a temperature sweep is associated to the starch gelatinization process and protein denaturation (Salvador et al., 2006). Therefore, when the temperature at which the maximum $\tan\delta$ value occurs is lower, it is assumed that the structure begins setting earlier. Sikora et al. (2010) successfully determined starch gelatinization temperature based on the mechanical spectra, complex moduli and $\tan\delta$.

After the temperature sweep, a new batter sample was employed in the measuring cell for an amplitude sweep (1 Hz at 20 °C) to determine the *linear viscoelastic range (LVE)*, *complex modulus (G^*)* and *yield strain*. Next, the flow properties of another new batter sample were studied using a shear rate ramp at 20 °C. The *apparent viscosity* was measured as a function of shear rate over the 0.1 - 10 s⁻¹ range. The viscosity was determined at shear rate 1.08 s⁻¹. Amplitude sweep and share rate ramp tests were performed in duplicate from different batter samples. All rheological tests were completed 2 hours after the preparation of the batter.

2.4. Texture Profile Analysis (TPA)

To analyze the textural parameters of the cake, 3 slices of 2 cm thickness were cut from the center of each cake. Two samples measuring 2.5 cm long × 2.5 cm wide × 2 cm high were cut from each slice. The samples were compressed to 80 % of their original height in a double cycle with a Texture Analyzer (TA-XT plus, Stable Micro Systems, Surrey, UK).

The test settings were: pre-test speed 1 mm s⁻¹, test speed 5 mm s⁻¹, post-test speed 5 mm s⁻¹, with a 5 s delay between the first and the second compression. The trigger force used was 0.05 N. The compression plate had a 75 mm diameter and the load cell weighed 50 kg. The samples were pressed parallel to the long axis of the loaf. The following textural parameters were calculated from the TPA graph: *Hardness* (N) was measured as the peak force on the 1st compression cycle and *cohesiveness* was calculated by the positive area during the 2nd compression cycle divided by the positive area during the 1st compression cycle, as a measure for structural integrity and resistance of a product against compression and tensile stress.

2.5. Statistical analyses

Regression models for the individual experimental responses were built in a stepwise fashion. First, a main effects model involving the two flour types and the three leavening acids was fitted. Next, the interactions of the five ingredients were added to the model, followed by the main effect of the mixing time. Finally, the model was refined by adding the interaction effects of mixing time and the ingredient proportions. At each step, the R² value was

studied as well as the significances (p-values) of the terms added to the model. All regression models were estimated using generalized least squares, to account for the correlation within the 10 block of 3 observations, in combination with residual maximum likelihood (REML) to estimate the run-to-run and block-to-block variation (Goos et al., 2006).

In order to explore the large data set of the responses, a biplot of the first two principal components was used. A biplot is a type of exploratory graph which summarizes information on a group of variables of a data matrix in two dimensions (Johnson and Wichern, 2002).

Partial least squares regression (PLSR) was used to model the cake volume and texture properties as a function of the batter rheological properties. By applying PLSR, multicollinearity and overfitting problems can be avoided (Everit and Dunn, 2001). PLSR solves these problems by searching for factors from the dependent variables (X) that are also relevant for the independent variables (Y). More specifically, a nonlinear iterative partial least squares (NIPALS) method was used to determine the latent variables. The software JMP 11 was used to apply PLSR to the data set. The K-fold validation method was applied with $k=5$. All variables were also tested by means of the variables importance plot (VIP). A variable was considered 'important' when its VIP value was greater than 0.8. The 7 independent variables, describing the batter rheological properties, could be summarized using only one factor, according to the Van der Voet (1994), in the case of cake *volume* and *cohesiveness*. Note that, due to their poor VIP value, the variables *Maxtan δ* and *G** were excluded from the model predicting *hardness*).

3. Results and discussion

3.1. Experimental design responses

A substantial block-to-block variance was observed for almost every response (results not shown), indicating that it was important to account for the day-to-day variation in the estimated regression models and the significance tests. Unlike the other responses, the *hardness* response did not show block-to-block variation.

A summary of all significant effects and the R^2 values of the various fitted regression models are presented in Table 1. Using models containing only the main effects of the ingredients and random effects to capture the day-to-day variation, the R^2 value was at least 70% for almost each response. For *batter density*, *Maxtan δ* , *TminG'*, *yield strain* and *apparent viscosity*, the R^2 values of the main-effects model involving the ingredient proportions were even larger than 80%. However, for the *Tmaxtan δ* and *hardness* responses, the model produced R^2 values of only 42% and 19%, respectively.

In the main-effects models, a large impact of the two flours was observed for all responses. In contrast, the difference in impact from the three leavening acids was significant only for the responses *Maxtan δ* , *volume* and *hardness*.

In the next step of our analysis, all two-way interactions between the basic ingredients, flours and leavening acids, were added to the model. Adding the interactions resulted in an increase of the R^2 value to 63% for *Tmaxtan δ* and to 65% for *hardness*. For most of the responses, there was a significant interaction effect between the two flours. In contrast, there were almost no significant interaction effects present between the leavening acids, or between the flours and the leavening acids.

The mixing time had a significant main effect for *hardness*, which increased with the mixing time. For several responses, we identified significant interaction effects between the mixing time, on the one hand, and the flour proportions, on the other hand. The interpretation of this kind of interaction is that the impact of the mixing time on the response depends on the exact mixture of flours. The mixing time had significant interaction effect with the leavening acids only in the case of the response *Tmaxtan δ* .

In the next paragraphs, first, the effects of flour mixture composition and its interaction effect with mixing time are discussed, followed by the effects of the leavening acid composition and its interaction effect with mixing time.

Because regression models involving multiple interaction effects are hard to interpret, the fitted models are represented graphically, using prediction profiles. These profiles show the effect of the various explanatory variables on the response in the fitted models. The prediction profiles have one panel per significant explanatory variable, and that panel visualizes the explanatory variable's effect for given values of all other explanatory variables in the fitted model. The given values of the explanatory variables are listed on the horizontal axes of the different panels and visualized using vertical dashed lines. On its vertical axis, a prediction profile shows the predicted response value corresponding to the given values of the explanatory variables. The predicted value is shown by means of the horizontal dashed line.

3.1.1. Effects of the flour mixture composition

Fig. 1 shows the significant interaction of the mixing time with the flour mixture composition for the *batter density*, *apparent viscosity* and *yield strain* responses. The three plots at the top in Fig. 1 show that mixing time has a negative effect on the batter density, apparent viscosity and yield strain when a limited amount of pregelatinized flour is utilized. The three middle plots in Fig. 1 show that the mixing time has virtually no effect when the proportion of pregelatinized flour is in the range of 8.5 - 13%. The batter density, apparent viscosity and yield strain are then insensitive to the mixing time. Finally, the three bottom plots show that mixing time has a substantial positive effect

when the proportion of pregelatinized flour is increased to 25%. The positive and negative effects of the mixing time are depicted using increasing and decreasing black lines in the prediction profiles in Fig. 1.

Fig. 1 also shows that using more pregelatinized flour results in a nonlinear increase in batter density, apparent viscosity and yield strain. The nonlinearity in the increase is more pronounced for the batter density response than for the other two responses, and is due to the interaction effect between the two flour types.

Replacing standard by pregelatinized flour influenced the size and the shape of the flour particles and the lubrication conditions affecting the flow properties. Pregelatinized flour absorbs more water, and therefore reduces the amount of the available water in the batter system (Alavi et al., 2002). When using larger quantities of standard flour, more water is available, which lubricates the particles and enhances their flow. On the other hand, when more than 14% of pregelatinized flour is used, at the expense of standard flour, the batter becomes more elastic during mixing time, as indicated by the *Intersection point (IP)* response.

Moreover, pregelatinized flour had an effect on the other viscoelastic properties as measured by the *LVE* and *G** responses, as well. The fact that these two responses increased when replacing standard with pregelatinized flour (results not shown) suggests a more stable and rigid batter. Similarly, Hesso et al. (2015a) found that the replacement of 20 % flour with pregelatinized starch produced an increase of batter's viscoelastic properties, resulting in low air incorporation during mixing, which is in agreement with the findings concerning *batter density* in the present study.

During the temperature sweep, batter with a large proportion of pregelatinized flour caused a decrease of the *Maxtan δ* response, which means that even during heating the elastic dominant behavior was more intense. The temperature at which the *Maxtan δ* occurs decreased in batters with a high proportion of pregelatinized flour. This is in line with the decrease of cake volume when a large proportion of standard flour is replaced with pregelatinized flour. However, for proportions of pregelatinized flour smaller than 5%, the cake volume was not influenced (Fig. 3). In the study of Seyhun et al. (2015), an even larger volume was observed in microwave baked cakes with 5% of flour substituted by pregelatinized starch. These findings support the idea that small quantities of pregelatinized flour could be acceptable in a cake formulation.

3.1.2. Effects of the leavening acids composition

An interesting interaction effect, between the leavening acids composition and mixing time, was observed for the *Tmaxtan δ* response (Table 1). The combination of much fast leavening acid with a long mixing time caused a decrease of *Tmaxtan δ* (Fig. 2). As a matter of fact, when much fast leavening is used in combination with long

mixing times, some of the CO₂ produced is removed from the batter during mixing. In addition, the smaller quantities of moderate and slow leavening acid in the mixture produced less CO₂ during baking.. A high amount of gas would impede heat transfer, but in the present case the smaller quantity of gas in the substrate allows faster heat transfer. Therefore, the lower $T_{maxtan\delta}$ could be translated into faster cake setting as well. Thus, the expansion of air bubbles during baking is allowed for a shorter period and the cake volume is smaller. When the setting of starch gelatinization occurs later at higher temperatures, the expansion of air bubbles during baking is allowed for longer period and consequently the cake volume is bigger (Mizukoshi et al., 1980).

The effect of a large amount of pregelatinized flour and fast leavening acid is a decrease in cake volume (Fig. 3). Book and Brill (2015) reported a strong negative correlation between the amount of CO₂ released in the batter prior to baking and the height of yellow cakes, as well. Additionally, Hesso et al. (2014) observed that cake porosity significantly decreased by the substitution of pregelatinized starches. Due to the results for the $T_{maxtan\delta}$, mixing time was expected to have a significant effect on cake volume response as well. However, we did not find such an effect, probably because the maximum mixing time used in this experiment was not long enough.

3.1.3. Effect of mixing time

3.2. Visualization of the relations between the responses

When performing a Principal Component Analysis of the response, 79,3 % of their variability was explained by the first two principal components (Fig. 4). Cake *hardness* was highly positively correlated to the $T_{minG'}$ response from the temperature sweep and negatively correlated to the $T_{maxtan\delta}$ values. Cake *cohesiveness* was highly negatively correlated to *apparent viscosity*, *yield strain* and *batter density*. Furthermore, a positive correlation of cake *cohesiveness* with $Maxtan\delta$ and cake *volume* was observed. On the other hand, cake *volume* was negatively correlated to *batter density*, *apparent viscosity* and *LVE*. In conclusion, the correlations suggest that it is possible to model cake volume and textural parameters as a function of batter rheological properties. Another interesting observation from the biplot is that cakes with a larger volume tend to have a higher cohesiveness and a lower hardness.

3.3. Regression model

3.3.1. Prediction of cake volume

The variation in the independent variables explained by the PLSR model is 71.66 % and the explained variation in the cake volume is 63.14 %. Diagnostic plots for the model residuals showed an adequate fit indicating that the

residuals behave normally. Table 2 shows the PLSR model's coefficients for centered and scaled data in order to reveal the latent structures.

High values of the viscoelastic properties (LVE , $TMinG'$, G^* , Y_s and *Apparent viscosity*) result in smaller cake volumes. In contrast, an increase of the $Maxtan\delta$ value and the corresponding temperature leads to an increase in cake volume. In conclusion, combining cake batter viscoelastic properties and flow properties provides a decent prediction of cake volume.

3.3.2. Prediction of cake textural parameters, hardness and cohesiveness

Applying the same PLSR method to predict hardness using batter rheological properties is not as successful as for predicting cake volume. Only 41.71% of the variation in cake hardness in our experimental data can be explained by the batter's rheological properties. On the other hand, the model's explained variation of the cohesiveness response was 74.93%.

Therefore, cohesiveness, defined as cake's tolerance to compressive and tensile stress, is very well predicted by the rheological properties of the cake batter. It can be hypothesized that the mechanical properties of the batter directly influence the mechanical strength of the cake solid phase, which determine the cohesiveness of cake. However, batter rheological properties can hardly predict cake hardness. Thus, the cake solid phase is expected to provide insufficient information about cake hardness as well. Additionally, the arrangement and microstructure of the particular elements in cake's cellular structure are anticipated to influence texture properties. Hence, the microstructural properties of cake are considered essential to enhance cake hardness prediction.

4. Conclusion

An innovative type of experimental design was successfully applied to better understand relationships of composition, processes, rheological batter properties and cake quality. The methodology used in this study was crucial to explore the influence of different parameters with a relatively small number of observations, limiting the experimental effort. Moreover, the interaction effects of the variables and their underlying relationships were quantified. This approach could be applied to other multifactorial processes, similar to cake baking.

All experimental factors considered in the above study, especially the type of flour, significantly influenced most of the measured responses; batter density, batter rheological parameters, cake volume and texture. Batter viscoelastic properties extracted from an amplitude and temperature sweep, together with viscosity, successfully predicted cake volume and cohesiveness. This means that a target recipe can be evaluated at the cake batter stage, thereby reducing the product and process development time. Cohesiveness is a critical textural property of

cake. A cohesive piece of cake remains in an unimpaired and complete state when handled during production, packaging and delivery.

To the contrary, hardness was only partially explained by the batter's properties. The hypothesis is that not only the batter rheological properties, but also the architecture of the cellular structure should be incorporated in the model to improve cake hardness prediction. The investigation of the relation between cake microstructure and cake texture will be part of further research.

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Table 1 Summary of responses modelling, including R² and P-values¹

Responses	Main effects			Interaction effects					Mixing time effect		Interaction of mixing time with mixture		
	R ²	Flours P -value	Leavening acids P-value	R ²	Flours P -value	Leavening acids P-value	Flour x leavening acid P-value		R ²	P -value	R ²	Flour mixture P -value	Leavening acid mixture P-value
Batter density (g/mL)	0.809	<0.001	-	0.815	<0.05	-	-		-	-	0.939	<0.05	-
Maxtanδ ²	0.984	<0.001	<0.05	0.989	<0.05	-	-		-	-	-	-	-
Tmaxtanδ (°C) ³	0.420	<0.001	-	0.628	<0.05	-	-		-	-	0.875	-	<0.05
TminG' (°C) ⁴	0.844	<0.001	-	0.959	<0.05	-	-		-	-	-	-	-
LVE ⁵	0.700	<0.001	-	-	-	-	-		-	-	-	-	-
G* ⁶	0.706	<0.001	-	0.740	-	0.06 ⁷	-		-	-	-	-	-
Yield strain (%)	0.834	<0.001	-	0.901	0.017	<0.05	-		-	-	0.981	<0.05	-
Apparent viscosity (Pa.s)	0.926	<0.001	-	0.978	<0.001	-	-		-	-	0.997	<0.05	-
Cake volume (mL)	0.783	<0.001	<0.05	0.873	<0.05	-	-		-	-	-	-	-
Hardness (N)	0.191	<0.001	<0.05	0.653	<0.05	-	-		0.771	<0.05	-	-	-
Cohesiveness	0.790	<0.001	-	0.907	-	-	<0.05		-	-	-	-	-

¹ R² values reported are the final R² values of the models including the effects of the previous steps as well. The effects are summarized per type, without showing the information about the exact ingredient's effect.

² Maximum tanδ during the temperature sweep

³ Temperature at which Maxtanδ occurs during temperature sweep

⁴ Temperature at which minimum storage modulus occurs during temperature sweep

⁵ Linear viscoelastic range

⁶ Complex modulus

⁷ Borderline significant

Table 2 Model coefficients for centered and scaled data to predict cake volume, cohesiveness and hardness

Variables	Cake volume	Cohesiveness	Hardness
Intercept	0.0000	0.0000	0.0000
LVE	-0.1254	-0.1320	0.1330
TMinG'	-0.1116	-0.1278	0.1466
G*	-0.1340	-0.1493	-
Yield strain	-0.1602	-0.1426	0.1481
Maxtan δ	0.1263	0.1742	-
Tmaxtan δ	0.1153	0.1258	-0.1605
Apparent Viscosity	-0.1598	-0.1664	0.1646

Fig. 1 Prediction profiles showing the dependence of the responses batter density, apparent viscosity and intersection point on the proportions of standard and pregelatinized flour and on the mixing time. From top to bottom, the profiles show the change in the effect of mixing time as the proportion of pregelatinized flour is increased from small to large. The values shown on the vertical axis are the predicted responses corresponding to the selected settings of the explanatory variables on the horizontal axis (indicated by vertical red dashed lines). The blue dashed lines represent the confidence intervals.

Fig. 2 Prediction profiles showing the dependence of the response Tmaxtan δ (Tmaxtandelta) on the proportions of standard flour, pregelatinized flour and leavening acids (fast: MCP; moderate and slow: SAPP 28 and SAPP 10) and on the mixing time. From top to bottom, the profiles show the change in the effect of mixing time as the proportions of fast leavening acid increase. The values shown on the vertical axis are the predicted responses corresponding to the selected settings of the explanatory variables on the horizontal axis (indicated by vertical red dashed lines). The gray zones represent the confidence intervals.

Fig. 3 Prediction profiles showing the dependence of the response cake volume on the proportions of standard flour, pregelatinized flour and leavening acids (fast: MCP; moderate and slow: SAPP 28 and SAPP 10). The values shown on the vertical axis are the predicted responses corresponding to the selected settings of the explanatory variables on the horizontal axis (indicated by red vertical dashed lines). The gray zones represent the confidence intervals.

Fig. 4 Biplot of all experimental responses

417

418

419

420

Fig. 1

Fig. 2

Fig. 3

Fig. 4

- The mixture of standard with pregelatinized wheat flour significantly influenced batter rheology and cake properties.
- A low amount of pregelatinized flour in the flour mixture caused a stable batter during mixing.
- The co-influence of the fast leavening acid with the mixing time on the start- up temperature of cake setting during baking.
- Cake volume and cohesiveness were well predicted by the rheological measurements.