Food Bioprocess Technol (2014) 7:2923–2930
DOI 10.1007/s11947-014-1254-5

ORIGINAL PAPER

Impact of Pregelatinized Starches on the Texture and Staling of Conventional and Degassed Pound Cake

Nesrin Hesso · Catherine Loisel · Sylvie Chevallier · Alain Le-Bail

Received: 10 October 2013 / Accepted: 6 January 2014 / Published online: 29 January 2014

Abstract The influence of selected pregelatinized starches on staling of pound cake has been investigated considering wheat and maize pregelatinized starches as flour substitutes. Two baking systems were considered to assess staling: a miniaturized baking system providing degassed baked batter and a conventional oven providing real products. Texture profile analysis, compression, and rupture tests were used to follow texture evolution during storage. Results confirmed the positive effect of partial substitution by pregelatinized starches in microcakes on retarding staling, while the denser structure of pregelatinized starch cakes prevented the same positive impact on texture and staling.

Keywords Wheat starch · Maize starch · Cake quality · Microcake · Dynamic mechanical analysis

Introduction

Cakes are complex systems in baking technology due to the presence of four main ingredients that are wheat flour, sugar, fat, and eggs in similar amounts and interacting together. The water content of a baked cake ranges between 18 and 28 %, which is intermediate between the one of bread and cookies or biscuits (Bennion and Bamford 1997 Wilderjans et al. 2013). The transformations taking place during cake baking are not yet fully understood. The final cake structure results from two main mechanisms: the formation of a solid matrix, thanks to starch gelatinization, and protein denaturation (Wilderjans et al. 2013), aerated by steam and carbon dioxide produced by the baking powders. Gelatinized starch is known to play a key role in the structural, textural, and physical properties of many foods, including bakery products (Marcotte et al. 2004). Starch gelatinization is affected by several parameters such as the baking process, baking temperature, and time; besides, the formulation and in particular the accessibility to water remains an important factor controlling the degree of starch gelatinization. Sakiyan et al. (2011) found that increasing the baking time favors the gelatinization for all baking processes (microwave, infrared–microwave combination and conventional oven) by increasing the final temperature of the cake; they also stated a higher gelatinization degree for conventional oven compared to the two other processes. Sánchez-Padro et al. (2008a) came to the same conclusion by investigating the characteristics of starch in pound cake crumb: higher moisture content was also observed for conventionally baked pound cake.

The physicochemical transformations of a cake continue after baking, which impairs the textural quality. The staling is the major factor which determines the shelf-life of cakes before microbial deterioration (Sozer et al. 2011).The staling of cakes during storage consists of an increase of the crumb firmness which results from two mechanisms: the moisture migration from crumb to crust (Baik and Chinachoti 2000) and the starch retrogradation (Cauvain 1998). According to Seyhun et al. (2005), the starch recrystallization causes an increased hardness of the cell wall material, which is supposed to be responsible for the firming of the stale crumb. Retrogradation behavior of rice cake has been studied by Ji et al. (2010): the main mechanism underlying the

N. Hesso · C. Loisel · S. Chevallier · A. Le-Bail
ONIRIS, BP 82225, 44322 Nantes, France

N. Hesso · C. Loisel (✉) · S. Chevallier · A. Le-Bail
LUNAM Université Nantes Angers Le Mans,
UMR 6144 GEPEA CNRS, 44602 Saint-Nazaire, France
e-mail: catherine.loisel@oniris-nantes.fr

changes in properties is suggested to be the slow amylopectin crystallization.

The staling rate is slower in cakes than in bread systems because of their higher ratios of sugar and shortening in the formulation (Sozer et al. 2011). However, it is still a problem in cake making and for consumer acceptance. High-quality cakes have various attributes including high volume, uniform crumb structure, softness, long shelf-life, and tolerance to staling (Gélinas et al. 1999). Gélinas et al. (1999) showed that staling was greatly reduced by partly replacing shortening by butter and glucose by sucrose. Quality, texture, and shelf-life of cakes were studied by Sánchez-Padro et al. (2008a, b), Gómez et al. (2007, 2008, 2010), Ji et al. (2010), Sozer et al. (2011), and Seyhun et al. (2005). According to Gómez et al. (2010), a high-quality layer cake was obtained by adding up to 20 % of an adequate fiber. Increasing the storage temperature to 20 °C and adding fiber minimized the firmness changes in sponge and layer cakes (Gómez et al. 2009). Purhagen et al. (2011) indicated that the quality can be improved by the addition of anti-staling agents like α-amylase, distilled monoglyceride, and lipase.

Hydrocolloids, enzymes, or starches of different origins were used in cakes to investigate shelf-life and to delay staling. Acceptance of yellow layer cakes was always improved by using hydrocolloids; for example, xanthan was able to prevent changes in texture during storage as shown by Gómez et al. (2007). Sozer et al. (2011) showed that a combination of gums, bacterial amylases, and pregelatinized starch yielded in a decrease of crumb hardness and toughness whereas springiness did not really change. Different starches were used in microwave-baked cakes by Seyhun et al. (2005) who found that the pregelatinized starch was the most effective starch to delay staling.

The objective of this investigation is to study the impact of selected pregelatinized starches on the initial texture and staling in the case of a pound cake recipe without any additives. The textural characteristics presented in the literature are mostly carried out by the Texture Profile Analysis test developed by Bourne (2002) which defines characteristics like hardness, springiness, and cohesiveness. The Young's modulus is another mechanical property often used to describe bread texture (Keetels et al. 1996a, b; Guessasma et al. 2008; Le-Bail et al. 2009). Other mechanical tests like dynamic oscillation and rupture tests have not been applied to cakes yet. The above-mentioned approaches have been considered in this study to monitor the texture evolution during staling. In addition, a specific methodology based on the study of the mechanical properties of degassed crumb has been considered to unravel the interaction between cellular structure and mechanical properties of the crumb material when texture has to be evaluated.

Materials and Methods

Materials

Wheat flour (14.8 % water content, 9.9 % protein, 1.1 % fat, 71.5 % starch, and 0.4 % ash) was supplied by Giraudineau (France); whole liquid eggs (0.8 % minerals, 12.1 % protein, 10.2 % fat, and 0.8 % carbohydrates) were purchased from Ovoteam (France). Fat consisted of rapeseed oil (70 %) and anhydrous milk fat (30 %) supplied by Corman (Belgium). Baking powder (sodium bicarbonate) was supplied by Brenntag. Pregelatinized wheat starch (PWS) and pregelatinized maize starch (PMS) were supplied by Roquette (France).

The reference recipe (recipe R) was close to pound cake recipe taken from Schirmer et al. (2012): 29.5 % wheat flour, 25 % sucrose, 25 % whole liquid eggs, 20 % fat, and 0.5 % sodium bicarbonate. Pregelatinized wheat starch recipe (recipe PWS) and pregelatinized maize starch recipe (recipe PMS) contained the same proportion of ingredients with 20 % of flour replaced by pregelatinized starch (wheat and maize, respectively).

Methods

Cake Baking

Batter Preparation The mixing method was a multistage mixing described by Wilderjans et al. (2008) with some modification to get a better air retention in the studied batter. Whole liquid eggs, sugar, and fat were mixed together in a first step using a Kitchen Aid mixer (KSM90, Kitchenaid, St. Joseph, MI) at speed 6 during 2 min. Then the flour and sodium bicarbonate were added and mixed at speed 8 during 3 min.

Cake Baking Two baking procedures were used: a conventional baking and a miniaturized baking procedure.

Conventional baking was performed in a ventilated oven using a prototype based on a domestic oven. The batter was placed in a baking plate with nine prints with about 40 g of batter in each print (the overall dimensions were 30×17.6 cm, and the dimensions of each print were 9×4.8×3 cm). The baking plate was installed in a preheated oven at 180 °C for 15 min, then cooled down to room temperature. Three recipes were baked: reference cake (cake R), pregelatinized wheat starch cake (cake PWS), and pregelatinized maize starch cake (cake PMS).

The miniaturized baking system (named “Peltier Oven”) is made up of two Peltier elements which can heat or cool the sample contacted onto their surfaces as proposed previously by Le-Bail et al. (2009). The following time–temperature profile has been used to mimic real baking conditions in the crumb as observed in the conventional baking procedure described above: heating from 20 to 98 °C during 10 min followed by a plateau at 98 °C during 5 min and a cooling step to 30 °C during 30 min. About 25–30 g of batter (without baking powder) was placed in plastic pouches, sealed under vacuum and placed in the Peltier oven. Three recipes were baked as the conventional baking: reference microcake (μcake R), pregelatinized wheat starch microcake (μcake PWS), and pregelatinized maize starch microcake (μcake PM).

Sample Preparation for Measurements The samples of microcakes after baking were cut in two different shapes: disks (7-mm diameter) and rectangles (35 mm×13 mm), both with height of 4 mm. The disks were placed in Eppendorf cones and the rectangular-shaped samples in plastic bags. Conventional cakes were placed in sealed plastic bags during storage.

Shelf-Life Protocol As cakes go stale slower than the bread, they need a longer shelf-life study (Cauvain 1998). All samples (microcakes and cakes) were stored at 10±1 °C during 40 days in a temperature-controlled, ventilated storage cabinet. They were removed from the storage cabinet just before the measurement.

Physical Analysis of the Batters and the Cakes

Water content was measured by drying at 105 °C overnight for batter, crumb, and crust for each recipe of fresh samples and during storage. The evolution of water migration between the crumb and crust during storage was then obtained. The measurements were made in triplicate. The crumb porosity was calculated according to Equation (1) with ρ_{ap} being the apparent density and ρ_s the solid density:

$$\text{Porosity} = 1\text{-}\rho_{ap}/\rho_s \quad (1)$$

The apparent density of the batter was evaluated by weighing a small sample of batter in a cup of known volume. The solid density was obtained by weighing the same volume of a degassed batter which was obtained after vacuuming the batter sample until 10 mbar using vacuum packaging Multivac C400. The apparent density of the cakes was measured using rapeseed replacement method (AACC 1991), and the solid density was measured by a helium pycnometer (Accupyc 1330, Micrometrics, Creil, France) in samples of 3–4 g. The porosity measurements were performed in triplicate.

Texture Analysis

Viscoelastic Properties of Fresh Microcakes

The samples were analyzed using the dynamic mechanical analyzer at ambient temperature (DMA Q800, TA Instruments–Waters LLC, 78 Guyancourt, France) by applying a frequency sweep on fresh rectangular microcakes with a dual cantilever clamp (Fig. 1). The frequency ranged from 1 to 10 Hz at 1 % strain and four replicates were carried out. Storage modulus and loss modulus were obtained in order to characterize the different recipes.

Texture Evolution During Storage of Micro- and Conventional Cakes

The evaluation of the texture of the microcake samples was based on the two types of deformation: a beam fracture test and a compression test. The objective was to get more information on the mechanical properties of the crumb assimilated to a cellular structure. The compression test was considered to mimic the compression of vertical cell walls (aligned with the deformation axis), whereas the beam fracture test was considered to mimic the rupture of the horizontal cell wall (perpendicular to the deformation of axis). The beam fracture test was performed on a Q800-DMA dynamic mechanical analyzer (Water Instruments) with a dual cantilever clamp (Fig. 1). A rectangular fresh or stale microcake was installed in the cantilever clamp; the sample was fixed on the lateral clamps, and the deformation was applied by the central clamp. The displacement ramp was set to 10,000 μm (initial displacement at 200 μm and initial strain of 0.2 %, initial force of 0.001 N). The force to strain plots was computed to obtain the maximal force exerted on the sample at rupture and the corresponding displacement.

The compression test of both micro- and conventional cakes was carried out with the Q800-DMA. A parallel plate system (15-mm diameter) was used to compress disks of microcakes (7-mm diameter, 4-mm height) or samples of conventional cakes (14-mm diameter, 10-mm height) after baking and during storage. The slopes of the stress-to-strain curves between 2 and 8 % strain for microcakes and 5 and 18 % for conventional cakes were computed to obtain the Young's modulus in the linear region considered as elastic.

A double compression test based on the texture profile analysis (TPA) developed by Bourne (Bourne 2002) was realized on the TA-XT+texture analyzer (Stable Microsystems, Surrey, UK) for conventional cakes: it was performed at 1 mm/s speed and 40 % strain with a 25-mm diameter probe, on disks of 25-mm diameter with at least three replicates for each sample during storage. The hardness (first force peak) and the cohesion (A2/A1; A1, first compression total area and A2, second compression total area) were calculated from the TPA curves.

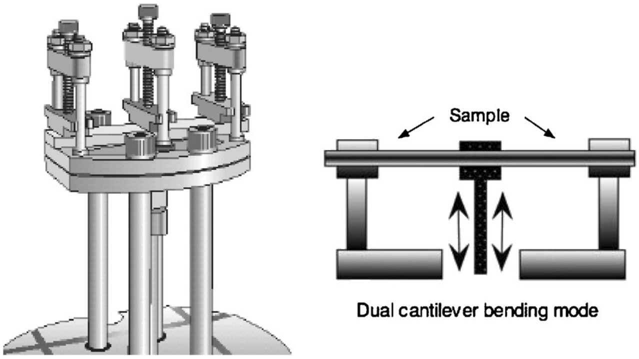


Fig. 1 Scheme of dual cantilever clamp used for rupture test with DMA

Statistical Analysis

Analysis of variance (ANOVA) was performed for testing the effect of the pregelatinized starches on the physical properties of the batter and on the texture of microcakes and conventional cakes during storage by using Statgraphics Centurion (Statpoint Technologies Inc., Sigma plus, France).

Results and Discussion

Texture is the most important property in bakery product design: it is linked to the micro- and macrostructural characteristics of foods, which determine their sensory perception. One of the major challenges in bakery products is not just to produce a high-quality product, but also to maintain the quality of freshly baked products during storage. The partial substitution of flour on cake quality with pregelatinized starches is supposed to retard staling. This effect was studied with two baking systems: microcake and conventional cake.

Effect of Partial Substitution of Flour by Pregelatinized Starches on Microcakes

Frequency Sweep

Figure 2 shows the effect of partial substitution of flour by pregelatinized starches (wheat and maize) on the storage and loss modulus of fresh microcakes. The conservative modulus (G') largely exceeds the loss modulus (G") that characterizes a rather rigid material. The partial substitution of flour by the pregelatinized starches clearly decreased the viscoelastic moduli, with the pregelatinized wheat starch offering the lowest values (about 50 % decrease). This means that pregelatinized starches give softer microcakes than the control fresh one. This result may be linked to the higher amount of gelatinized starch in the PWS and PMS cakes in comparison to the reference recipe; such trend has been observed by Seyhun et al. (2005) on white layer cake.

Rupture Test

The firmness of fresh and stale microcakes was tested by a rupture test as shown in Fig. 3. The rupture force decreased significantly for pregelatinized starches compared to the reference. This rupture force represents the force necessary to initiate cake rupture: the larger it is, the harder the cake is. For samples made with pregelatinized starches, no significant difference could be observed between fresh and stale samples unlike for the reference microcake (Fig. 3a). Concerning the displacement at rupture (Fig. 3b), it decreases for all samples over the staling period. The displacement at rupture represents the plastic deformation of the material reached before rupture; the higher the displacement, the higher the ductility of the material (Bourne 2002).The stale samples are then less ductile or, in other words, more brittle. The decrease is more accentuated for the reference microcake than for the two other microcakes. These results seem to indicate that the softness of fresh and stale samples is better preserved when pregelatinized starches are used in the recipe in our conditions.

Compression Test

The evolution of the Young's modulus during storage at 10 °C for the three microcakes is shown in Fig. 4. The Young's modulus significantly decreased with pregelatinized starches, with the PWS microcake presenting a lower modulus compared to the PMS. This confirms the positive effect of partial substitution of flour by pregelatinized starches as found previously (Fig. 3). The difference between the wheat and maize pregelatinized starches was already observed with the viscoelastic moduli (Fig. 2). The Young's modulus represents the stress related to the section of the microcake divided by the strain (2–10 %): the higher it is, the harder the product is, and, consequently, the more pronounced the staling is during storage. It appears from the curves of Fig. 4 that the kinetics of staling is modified by the substitution. For microcakes PWS and PMS, constant values of the Young's modulus are reached after 10 days of storage, while the Young's modulus continues to increase for reference cake even after 40 days. First-order kinetics model (Equation (2)) is used to fit the staling curves (Le-Bail et al. 2009; Ronda and Roos 2011). Two staling characteristic parameters are obtained: E_∞, which is the Young's modulus obtained at the end of staling and τ which is the characteristic time of the first-order model (time constant). E_0 represents the initial Young's modulus for the initial time (t=0).

$$\mathrm{E(t)} = \mathrm{E}_\infty + (\mathrm{E}_0 - \mathrm{E}_\infty)\mathrm{e}^{(t/\tau)} \quad (2)$$

Values of E_∞ obtained using Equation (2) with a regression model were 10.7, 4.0, and 3.4 kPa for reference microcake, microcake PWS, and microcake PMS, respectively. This

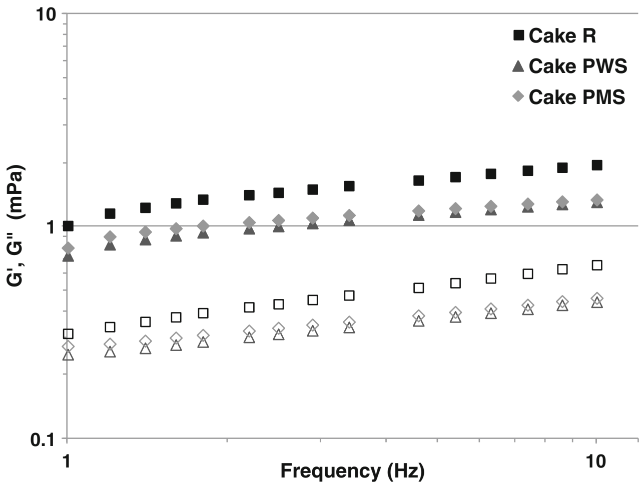


Fig. 2 Mechanical spectra of reference microcake (μCake R), pregelatinized wheat starch microcake (μCake PWS), and pregelatinized maize starch microcake (μCake PMS) at 1 % strain and 25 °C. *Filled symbols* are storage modulus G' and *empty symbols* are loss modulus G"

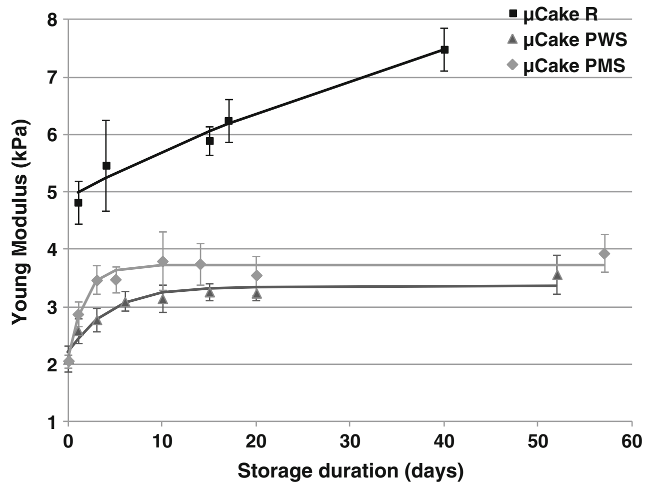


Fig. 4 Young's modulus (2–10 % strain) of microcakes as a function of storage period at 10±1 °C. Experimental measures are fitted with Equation (2) for each cake

confirms that the substitution of wheat starch by pregelatinized starches decreases significantly the Young's modulus even after 40 days. The τ values were 69, 5, and 3 days for reference microcake, microcake PWS, and microcake PMS, respectively. It appeared that crumb made from PWS and PMS reached the end of staling much faster, whereas the completion of staling was much slower for the reference microcake. It seemed that the completion of staling which encompasses starch retrogradation was much faster for microcakes.

To conclude, the texture of fresh and stale microcake samples was significantly softer, thanks to partial substitution of flour with both pregelatinized wheat and maize starches, with a good agreement between the three texture tests. The staling increased the rupture force and the Young's modulus. Considering the staling kinetics, the PMS and PWS microcakes reaches the E_∞ values conversely faster to the reference microcake which continues staling even after 40 days with higher values. It is important to consider that this study was carried out on a microcake, which means on a degassed material without any cells in the crumb.

Effect of Partial Substitution of Flour by Pregelatinized Starches on Conventional Cakes

Water Content

The water content of batter, crust, and crumb for the three recipes is shown in Table 1. No significant difference between the water content of the three recipes for batter or crust was observed. An increase in crumb water content was found for the pregelatinized starch recipe. This may be related to higher water holding capacity of pregelatinized starches compared to the reference (Seyhun et al. 2005).

Compression and Porosity Tests

The rating of the staling during storage by the measurement of the Young's modulus on conventional cakes is shown in

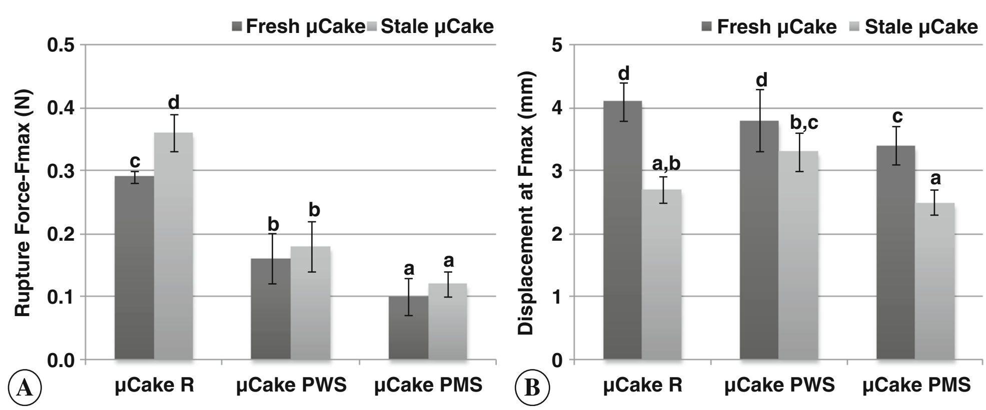
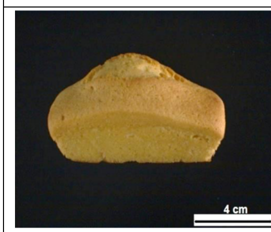
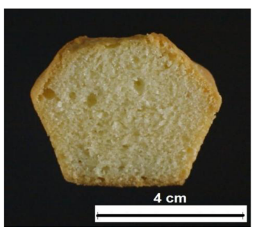
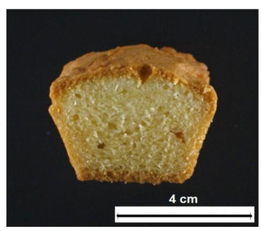
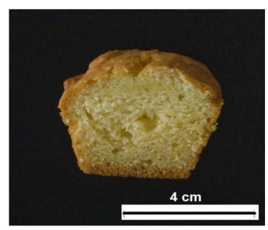


Fig. 3 Rupture force (**a**) and displacement (**b**) for fresh and stale microcake samples (35×12×4 mm). *Bars* with a *letter* in common in the same figure are not significantly different ($p<0.05$)

Table 1 Physical and textural properties of the studied recipes: recipe R (reference), recipe PWS (pregelatinized wheat starch), and recipe PMS (pregelatinized maize starch)

Parameters		Recipe R	Recipe PWS	Recipe PMS
Water content %	Batter	23.3±0.1a	23.5±0.1b	23.2±0.1a
	Crust	8.2±0.2a	7.7±0.0a	7.7±0.1a
	Crumb	17.4±1.1a	20.5±0.3c	19.3±0.6b
Porosity %	Batter	26.8±0.8c	21.4±0.7a	24.5±1.3b
	Cake	69.7±1.3b	54.5±0.5a	53.5±3.6a
Cake texture during storage at 10 °C				
Hardness *n*	Day 0	4.1±0.2a	5.5±0.6b	5.9±0.6b
	Day 20	8.1±1.3a	12.5±1.9b	12.8±1.8b
Cohesion (A2/A1)	Day 0	0.74±0.07a	0.71±0.05a	0.73±0.03a
	Day 20	0.59±0.05a	0.60±0.02a	0.59±0.02a

Recipe R	Recipe PWS	Recipe PMS
		
		

Different letters in the same line indicate that statistically significant differences exist at $p<0.05$

Fig. 5. The partial substitution of flour by pregelatinized starches does not change the Young's modulus. As observed on Fig. 5, the Young's modulus evolution during storage is not significantly different from the one of the reference cake conversely to the microcakes. Therefore, no improvement of the texture in conventional cakes compared to microcakes was observed.

The porosity of the batter and cakes of the recipes is presented in Table 1 to better understand the transformations of the cakes. The partial substitution of flour by pregelatinized starches decreases the batter porosity. This can be explained by a reduction of gas retention in batter during mixing when pregelatinized starches are used. When the batter is baked, the cake porosity is further significantly decreased by the substitution (Table 1). This may be explained by the fact that the amount of nongelatinized starch in the batter is reduced. The swelling of starch occurs then at lower temperature, and the texture sets before the complete gas release of the baking powder. This gives a compact texture with less aeration (lower porosity) compared to the reference cake R, as can be observed on the pictures (Table 1). The decrease of the cake porosity should lead to higher Young's modulus, but no difference was found between the three cakes (Fig. 5). To explain this result, one has to consider the properties of the microcakes that represent the solid part, i.e., the matrix of the cellular structure of the cake. Microcakes of pregelatinized starches exhibit lower Young's modulus than the reference.

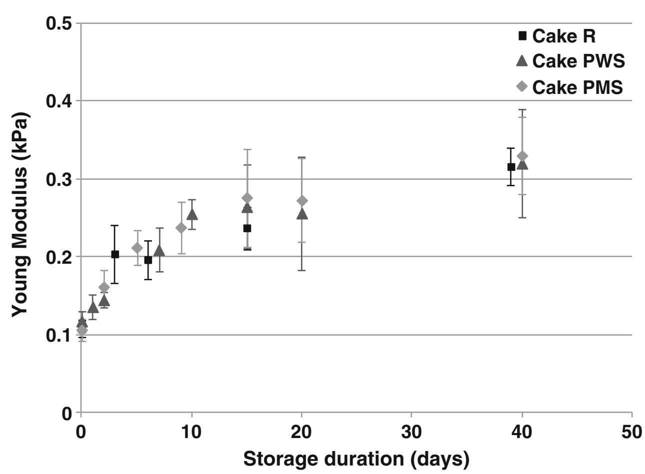


Fig. 5 Young's modulus (5–18 % strain) of conventional cakes as a function of storage period at 10±1 °C

The resulting softening of the crumb matrix may in turn compensate the decrease in porosity, leading to the same values for reference and conventional cakes.

The mechanical behavior of porous material has been studied by several researchers and in particular by the pioneering publication of Gibson and Ashby (1997). A model has been proposed by these authors for different foams with open cells, to describe the relationship between the relative density and the relative Young's modulus (Equation (3)). This model has been used by other authors such as Guessasma et al. (2008) and Keetels et al. (1996b) in the case of bakery products:

$$E^*/E = (\rho^*/\rho)^2 \quad (3)$$

E^* and E represent the Young's modulus of the cellular system (conventional cake) and the solid material (microcake) respectively; ρ^* and ρ represent the density of cellular solid and of the solid material, respectively. The results obtained from these three cakes during storage are presented in Fig. 6. The results show a higher relative Young's modulus than predicted by the model of Gibson and Ashby (1997). The difference between the experimental data and the model could be explained by the presence of partially closed cells in the cake. During compression test, the mechanical properties of a cellular system are generated by a combination of the mechanical resistance of the cellular matrix and also by the force needed to compress the gas enclosed in the cells. The relative Young's modulus of the substituted cakes is closer to the Gibson and Ashby model than the reference cake. This may be explained by the more compact structure of the substituted cakes as deduced from the pictures of Table 1.

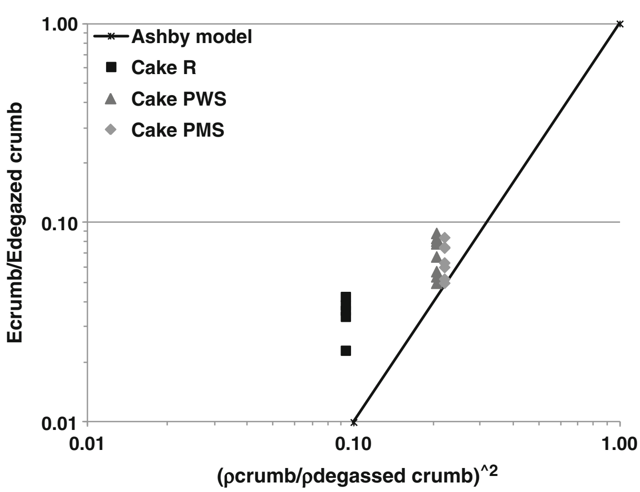


Fig. 6 Relative Young's modulus ($E^*_{\mathrm{crumb}}/E_{\mathrm{degassed\ crumb}}$) as a function of the relative crumb density (ρ crumb/ρ degassed crumb) during storage at 10±1 °C for reference and pregelatinized starch cakes in comparison with Gibson and Ashby model (*fitted curve*) (Gibson and Ashby 1997)

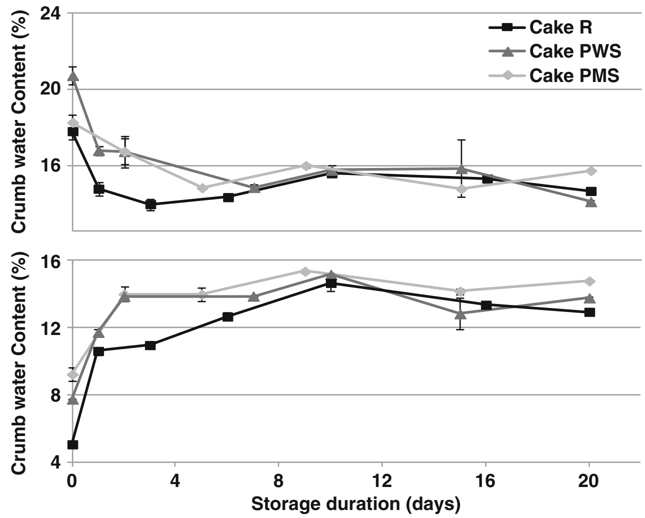


Fig. 7 Crust and crumb water as a function of storage period at 10±1 °C of the three conventional cakes

Texture and Water Content of Conventional Cake During Staling

The rigidity of the conventional cake has been evaluated by the Young's modulus at low strain (Fig. 5), but this does not match the sensorial perception of the texture that needs larger strain (at least 40 %) to be investigated. The TPA test completes the previous results, particularly the hardness and cohesion characteristics. The effect of pregelatinized starches on cake hardness and cohesion is presented in Table 1. The PWS and PMS cakes are harder than the reference which can be attributed to their lower porosity. The hardness clearly increases during storage (day 0 and day 20) while the cohesion slightly decreases for all cakes.

Another parameter which is responsible for cake staling is the water migration between crust and crumb during storage (Baik and Chinachoti 2000; Cauvain 1998). Crust and crumb water contents were measured in cakes during staling (Fig. 7). Results show that crust water content increased during staling, contrary to the one in the crumb which decreased for all cakes. As expected, the water migrated from crumb to crust to reach equilibrium in water activity for all recipes after 10 days of storage. This migration may partially explain the hardening of the texture of the crumb during storage.

Conclusions

The textural characteristics of pound cakes were evaluated during storage, and the flour was partially substituted by pregelatinized wheat and maize starches in order to reduce the staling. The microstructure of the cake can be assimilated to a cellular system, composed of air cells dispersed in a solid matrix. Two systems were considered: the microcakes that mimic the matrix and the conventional cakes. The viscoelasticity and textural properties of the microcakes at low strain (Young's modulus) or large strain (rupture force) highlight the ability of the pregelatinized starches to, on one hand, increase the softness of the cake material and on the other hand, attenuate the effect of staling, as can be deduced from the evolution of the rupture force and the Young's modulus.

Concerning the effect of the pregelatinized starches on conventional cakes, the major conclusion is that neither the rigidity expressed by the Young's modulus nor the hardness measured at large strain (40 %) could indicate any reduction of the staling.

These results emphasize the main role of the alveolar structure of the cake on its textural properties. To compare the effect of any substitute, one has to consider the same porosity which can be obtained by modulating the kind and content of the rising agents.

This study highlights the interest of studying the properties of the microcakes for which no interplay of the porosity is possible. It also shows that combining the textural methods contributes to a better understanding of the properties of the cakes.

Acknowledgments This work has been supported by a grant no /664/H (first year of Ph.D.) and by a financial support from GEPEA-ONIRIS at follows. Luc Guihard and Christophe Couëdel are gratefully acknowledged for the realization of a prototype based on a domestic oven (named "Peltier Oven"), and Delphine Queveau is also gratefully acknowledged for her help in the thermal analysis.

References

AACC. (1991). *Approved methods of the AACC, Method 10-91. American Association of Cereal Chemists*. MN, USA: St Paul.

Baik, M.-Y., & Chinachoti, P. (2000). Moisture redistribution and phase transitions during bread staling. *Cereal Chemistry, 77*(4), 484–488.

Bourne, M. (2002). *Food texture and viscosity: concept and measurement* (2nd ed., pp. 182–186). New York, USA: Academic Press, Elsevier Science.

Bennion EB & Bamford GS (1997) *The technology of cake making*. Ed by Bent A J. Blackie Academic and Professional, London, UK.

Cauvain, S. P. (1998). Improving the control of staling in frozen bakery products—a review. *Trends in Food Science & Technology, 9*(2), 56–61.

Gélinas, P., Roy, G., & Guillet, M. (1999). Relative effects of ingredients on cake staling based on an accelerated shelf-life test. *Journal of Food Science, 64*(5), 937–940.

Gibson, L. J., & Ashby, M. F. (1997). *Cellular solids. Structure and properties*. Cambridge, UK: Cambridge University Press.

Gómez, M., Ronda, F., Caballero, P., Blanco, C., & Rosell, C. M. (2007). Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. *Food Hydrocolloids, 21*(2), 167–173.

Gómez, M., Oliete, B., Rosell, C. M., Pando, V., & Fernández, E. (2008). Studies on cake quality made of wheat–chickpea flour blends. *LWT - Food Science and Technology, 41*(9), 1701–1709.

Gómez, M., Elena Ruiz-Paris, B. O., & Pando, V. (2009). Modeling of texture evolution of cakes during storage. *Journal of Texture Studies, 41*(9), 17–33.

Gómez, M., Moraleja, A., Oliete, B., Ruiz, E., & Caballero, P. (2010). Effect of fiber size on the quality of fiber-enriched layer cakes. *LWT - Food Science and Technology, 43*(1), 33–38.

Guessasma, S., Babin, P., Della Valle, G., & Dendievel, R. (2008). Relating cellular structure of open solid food foams to their Young's modulus: finite element calculation. *International Journal of Solids and Structures, 45*(10), 2881–2896.

Ji, Y., Zhu, K., Zhou, H., & Qian, H. (2010). Study of the retrogradation behaviour of rice cake using rapid visco analyser, Fourier transform infrared spectroscopy and X-ray analysis. *International Journal of Food Science and Technology, 45*, 871–876.

Keetels, C. J. A. M., van Vliet, T., Jurgens, & Walstra, P. (1996a). Effects of lipid surfactants on the structure and mechanics of concentrated starch gels and starch bread. *Journal of Cereal Science, 24*(1), 33–45.

Keetels, C. J. A. M., van Vliet, T., Jurgens, A., & Walstra, P. (1996b). Relationship between the sponge structure of starch bread and its mechanical properties. *Journal of Cereal Science, 24*(1), 27–31.

Le-Bail, A., Boumali, K., Jury, V., Ben-Aissa, F., & Zuniga, R. (2009). Impact of the baking kinetics on staling rate and mechanical properties of bread crumb and degassed bread crumb. *Journal of Cereal Science, 50*(2), 235–240.

Marcotte, M., Sablani, S. S., Kasapis, S., Baik, O.-D., & Fustier, P. (2004). The thermal kinetics of starch gelatinization in the presence of other cake ingredients. *International Journal of Food Science and Technology, 39*(7), 807–810.

Purhagen, J. K., Sjöö, M. E., & Eliasson, A.-C. (2011). Starch affecting anti-staling agents and their function in freestanding and pan-baked bread. *Food Hydrocolloids, 25*(7), 1656–1666.

Ronda, F., & Roos, Y. H. (2011). Staling of fresh and frozen gluten-free bread. *Journal of Cereal Science, 53*(3), 340–346.

Sakiyan, O., Sumnu, G., & Sahin, S. (2011). A study on degree of starch gelatinization in cakes baked in three different ovens. *Food Bioprocess Technology, 4*, 1237–1244.

Sánchez-Padro, M. E., Ortiz-Moreno, A., Mora-Escobedo, R., Bello-Pérez, A., Hernani, Y.-M., & Ramos-Lopez, G. (2008a). Effect of baking method on some characteristics of starch in pound cake crumbs. *Journal of the Science of Food Agriculture, 88*, 207–213.

Sánchez-Padro, M. E., Ortiz-Moreno, A., Mora-Escobedo, R., Chanona-Pérez, J. J., & Necoechea-Mondragón, H. (2008b). Comparison of crumb microstructure from pound cakes baked in a microwave or conventional oven. *LWT - Food Science and Technology, 41*(4), 620–627.

Seyhun, N., Sumnu, G., & Sahin, S. (2005). Effects of different starch types on retardation of staling of microwave-baked cakes. *Food and Bioproducts Processing, 83*(1), 1–5.

Sozer, N., Bruins, R., Dietzel, C., Franke, W., & Kokin, J. L. (2011). Improvement of shelf life stability of cakes. *Journal of Food Quality, 34*(1745), 151–162.

Schirmer, M., Jekle, M., Arendt, E., & Becker, T. (2012). Physicochemical interactions of polydextrose for sucrose replacement in pound cake. *Food Research International, 48*, 291–298.

Wilderjans, E., Pareyt, B., Goesaert, H., Brijs, K., & Delcour, J. (2008). The role of gluten in a pound cake system: a model approach based on gluten–starch blends. *Food Chemistry, 110*, 909–915.

Wilderjans, E., Luyts, A., Brijs, K., & Delcour, J. (2013). Ingredient functionality in batter type cake making. *Trends in Food Science & Technology, 30*(1), 6–15.