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Cake Baking with Alternative Carbohydrates for Potential Sucrose Replacement. I. Functionality of Small Sugars and Their Effects on High-Ratio Cake-Baking Performance

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ABSTRACT

For exploring the effects of sugar type on predictive Differential Scanning Calorimetry (DSC), Rapid Visco-Analyzer (RVA), and cake baking, including time-lapse photography analyses, xylose (X), glucose (G), fructose (F), and sucrose (Su) were selected as a diagnostic series of small sugars. The effects of chlorination on Solvent Retention Capacity (SRC), wheat flour starch gelatinization and pasting and of sucrose particle size on cake baking were also examined. DSC and RVA results showed that 50 w% sugar solutions retarded starch gelatinization and enhanced starch pasting for both non-chlorinated and chlorinated flours, respectively. Chlorination did not affect starch gelatinization, but enhanced earlier pasting and resulted in higher viscosity. Cake baking with chlorinated flour showed a similar pattern for height of cake center and height of cake edge, but a different pattern for cake shape factor. More rapid sugar dissolution of sucrose with smaller particle size resulted in exaggerated collapse. The use of time-lapse photography and interpretation of the expansion profiles during baking of cakes made with the diagnostic series of sugars led to a deeper understanding about cake-baking performance, which makes it possible to relate RVA behavior in diagnostic sugar solutions to cake-baking potential, and to guide wheat-breeding efforts to provide functional flours for baking of high-ratio-type cakes.

INTRODUCTION

Cakes and cookies are typically similar in formula, with high sugar concentrations and high fat levels, but they are different in wheat flour type and water level. Typical low-moisture cookies are made with unchlorinated flour and low water levels, while typical high-ratio cakes are made with chlorinated flour and high water levels. Chlorination is an essential (soft wheat) flour treatment for producing high-ratio cakes, and it affects flour components such as starch, proteins, arabinoxylans, and lipids, resulting in enhanced starch pasting, increased hydrophobicity of starch granule-surface proteins, oxidative gelation of arabinoxylans, and decreased gluten strength (Holme 1962; Cole 1970; Kissel 1971; Kulp et al 1972; Kissel et al 1979; Gaines and Donelson 1982; Huang et al 1982a, 1982b; Donelson et al 1984; Telloke 1985; Conforti et al 1993; Duviau et al 1996; Baldwin et al 1997; Kweon et al 2009a, 2009b). Differences in water level result in differences in % sugar concentration (%S) and total solvent (TS) between cookies and cakes. The formula for an AACC Method 10-53.01 wire-cut cookie is 66 %S and 64 TS, while that for an AACC Method 10-90.01 cake is 50.9 %S and 275 TS (AACCI 2009).

Although sucrose is the most commonly used sugar for baking, consumers' recent interests in healthier baked products made with other sugars and sugar alcohols are increasing, because of lower glycemic index and prebiotic nutritional benefits. Numerous researchers have reported studies on cookies made with various sugars (Curley and Hosney 1984; Doescher and Hosney 1985; Doescher et al 1987; Nishibori and Kawakishi 1992; Zoulias et al 2000; Gallagher et al 2003; Kweon et al 2009c, 2010a, 2016; Laguna et al 2013), but there have been fewer reported studies on cakes made with various sugars and sugar replacers (Bean et al 1978; Hicsasmaz et al 2003; Ronda et al 2005; Schirmer et al 2012). Miller and Trimbo (1965) showed that the

gelatinization temperature of starch in cake batter is an important factor in determining cake quality. Bean et al (1978) reported that the delaying effect of sugars on starch gelatinization appeared to be a major factor in determining layer cake volume and contour, so the effect of sugar type on cake qualities must be assessed for successful substitution of sugars.

Different sugars at the same solution concentration produce different extents of increasing starch gelatinization temperature (Bean and Yamazaki 1978; Bean et al 1978; Spies and Hosney 1982; Slade and Levine 1987). Slade and Levine (1994) reported that 50% w/w sugar solutions retard mixograph development times at 25°C, and retard starch gelatinization to higher temperatures; both effects correlate highly with dielectric rotational relaxation times. They noted that the rotational relaxation time allows a direct comparison of the mobility of a sugar solution and its relative effectiveness as a plasticizer, compared to water. The solubility parameter (SP) values are different for different sugars, decreasing in the order water > fructose > sucrose > xylose > glucose. For comparable crystalline particle sizes, the saturation concentrations for these sugars at 25 °C are: fructose, 80.0 w%; sucrose, 67.9 w%; xylose, 55.6 w%; and glucose monohydrate, 51.1 w%.

The generic behavior of sugars in concentrated aqueous solutions is modulated by differences in their physical chemistry and glass-forming functionality (Slade and Levine 1988). In the present study, in order to explore the effects of sugar type on results from DSC, RVA, and cake baking, xylose, glucose, fructose, and sucrose were selected as a diagnostic series of small sugars. The effects of chlorination on flour functionality, starch gelatinization, and starch pasting, and the effect of sucrose particle size on high-ratio caking-baking performance, were also explored.

MATERIALS AND METHODS

Materials

‘Croplan 594W’ (soft red winter) wheat cultivar was tempered (to 14% moisture) and milled, using a Miag Mill for producing patent flour (55% milling yield/cleaned wheat, 33% break flour yield). The flour contained 13.6% moisture, 6.8% protein, and 0.324% ash, and a portion of the flour was chlorinated to pH 4.6 for cake baking. Xylose, fructose, glucose, and sucrose were reagent grade, and used for DSC, RVA, and cake baking (except for sucrose). For cake baking with sucrose, Baker’s special sugar – ultrafine-granulated (sucrose UF) (C&H) and fine-granulated sugar (sucrose FG) (Domino) were used, and a commercial hydrogenated all-vegetable shortening, Crisco (Smuckers, Orville, OH), was used. All other chemicals were reagent grade.

Methods

Flour Quality Analyses Using SRC

Non-chlorinated and chlorinated flour samples were analyzed by SRC testing (Kweon et al 2011), to evaluate the changes in flour functionality caused by chlorination. The pH’s for the flour samples were measured on 10 w% aqueous flour slurries, using a pH meter (Fisher Scientific, Pittsburgh, PA). SRC tests in four solvents were done according to AACC Method 56-11.02 (AACCI 2009). Each flour sample (5 g) was mixed and suspended well with 25 g of each solvent (deionized water, 5% (w/w) lactic acid in water, 5% (w/w) sodium carbonate in water, and 50% (w/w) sucrose-water), and hydrated for 20 min, with manual shaking at each 5 min interval. The hydrated flour slurries were centrifuged at 1000 x g for 15 min, and the

supernatants were drained for 10 min. Each wet pellet was weighed, and the SRC value for each sample was calculated according to the Method.

Starch Gelatinization and Pasting Properties, Measured Using DSC and RVA

Wheat flour starch gelatinization behavior in each sugar solution was analyzed using DSC.

According to the methodology of Kweon et al. (2009c, 2010a), one part by weight of flour and one part of 50% (w/w) sugar solution were mixed (by hand with a spatula), and about 40 mg of the mixture were transferred to a stainless steel DSC pan (Perkin-Elmer), and the pan was hermetically sealed. Each sample was heated in the DSC instrument (DSC-7, Perkin-Elmer, Norwalk, CT) from 30 to 130°C, with a 10 °C degree min⁻¹ heating rate, and an empty DSC pan was used as a reference. DSC calibration and other aspects of DSC methodology were as previously reported (Kweon et al. 2009, 2010a). DSC analysis for each sample was done at least in duplicate.

Wheat flour starch pasting behavior in each sugar solution was analyzed using RVA (Newport Scientific Pty. Ltd., Warriewood, Australia). According to the methodology of Kweon et al. (2009c, 2010a), flour (3.5 g, 14% moisture basis) was added to 25 ml of water or 50% (w/w) sugar solution, and mixed thoroughly. The flour mixture was run using the following Standard 1 RVA profile (Newport Scientific): hold the sample at 50 °C for 1 min, heat from 50 to 95°C at 12.2 °C min⁻¹, hold at 95°C for 2.5 min, cool to 50°C at 12.2 °C min⁻¹, and hold at 50°C for 2 min. RVA analysis for each sample was done at least in duplicate.

Cake Baking with Various Sugars

AACC Method 10-90.01 cake baking (AACCI 2009) was used with minor modifications (Kweon et al. 2010b), and the basic ingredients and formula are shown in Table 1. As in our previous study of cookie baking (Kweon et al. 2009c), two different crystal sizes of sucrose (sucrose UF and sucrose FG) were used to investigate the effect of sugar particle size on cake baking. Glucose monohydrate was used instead of anhydrous glucose, with appropriate adjustment of formula water. Only chlorinated flour was used for cake baking. For baking cakes with different sugars, sucrose was replaced by each other sugar, and cake baking was done in duplicate. Before placing a baking pan containing about 380 g of cake batter into the oven, a batter plus a baking pan were weighed. After baking at 340°F for 35 min, the cake plus the baking pan was removed from the oven and weighed immediately, in order to calculate weight loss during baking. Cakes were cooled for 4 hr, and the height of cake edge (HCE) and height of cake center (HCC) were measured. The cake shape factor (SF) was calculated from HCC divided by HCE. Also, time-lapse photographs were taken at 5 min intervals, through a glass window in the oven door, to observe the changes in cake geometry during baking.

Statistical Analysis

Statistical analyses of SRC were performed by t-test, and cake-baking data by Tukey-Kramer HSD multiple comparison of means, using JMP for Windows (Version 12.0, SAS, Cary, NC, USA).

RESULTS AND DISCUSSION

Flour Characteristics

SRC results for the flour samples are presented in Table 2. SRC values for the non-chlorinated flour were 44.2% water SRC, 87.2% lactic acid SRC, 57.1% sodium carbonate SRC, and 78.4% sucrose SRC, while those for the chlorinated flour were 49.3% water SRC, 77.3% lactic acid SRC, 58.0% sodium carbonate SRC, and 85.6% sucrose SRC. As reported previously (Kweon et al 2009a, 2011), SRC values for the chlorinated flour were higher than those for the non-chlorinated flour, except for the lactic acid SRC value. The lower lactic acid SRC value for the chlorinated flour indicated the decrease in glutenin functionality resulting from chlorination. This large effect on lactic acid SRC value is due to the loss of glutenin network formation, because of an absence of disulfide exchange (Kweon et al 2011). Slightly higher sodium carbonate SRC and much higher sucrose SRC values for the chlorinated flour indicated an increased extent of swelling of solvent-accessible amylopectin, rather than increased damaged starch, and possible oxidative gelation of solvent-accessible arabinoxylans accounted for the dramatic increase in arabinoxylan network swelling due to chlorination, respectively, as explained previously (Kweon et al 2009b).

Starch Gelatinization Characteristics for Non-Chlorinated and Chlorinated Flours

The DSC results for the chlorinated flour in various 50% (w/w) sugar solutions were very similar to those for the non-chlorinated flour, which indicated that there was no significant effect of chlorination on starch gelatinization (Fig. 1). For both flour samples, the DSC thermograms showed retardation of gelatinization in the sugar solutions, in the order water < X < F < G < Su. Abboud and Hosney (1984) and Kim and Walker (1992) showed similar results for the effects of different sugars on gelatinization of non-chlorinated wheat starch in about 50-51% sugar solutions. The peak temperatures for gelatinization of the chlorinated flour starch in each solvent

(sugars completely pre-dissolved) were 63.6°C in water, 77.4°C in X, 81.7°C in F, 84.2°C in G, and 92.5°C in Su, which were not significantly different from those for the non-chlorinated flour in the same solvents: 63.4°C in water, 76.6°C in X, 81.7°C in F, 84.3°C in G, and 92.0°C in Su. Huang et al (1982b) showed similarly that chlorination did not alter the DSC gelatinization phase transition in either simple (flour-water) or complex batter systems. Allen et al. (1982) likewise reported that chlorine treatment did not affect significantly the transition temperatures or enthalpies for the flour or the starch isolated from it.

Starch Pasting Characteristics for Non-Chlorinated and Chlorinated Flours

RVA results for both flour samples showed enhanced initial pasting (i.e. start of viscosity increase at lower temperature), in the order $X > F > G > Su$ (Fig. 2), which was the reverse order for the retardation of starch gelatinization, from DSC. Extensive chlorination (to pH 4.6) does not affect the gelatinization temperature for starch, as measured by DSC, but pasting of starch, for the chlorinated flour starch in concentrated (50% w/w) aqueous sugar solutions, occurred earlier and at lower temperature. In contrast, pasting could not occur for the non-chlorinated flour in the same anti-plasticizing environments: 66.2 vs. 69.8°C in water, 90.3 vs. 91.1°C in sucrose, 82.2 vs. 83.1°C in fructose, 85.5 vs. 86.5°C in glucose monohydrate, and 78.2 vs. 79.1°C in xylose, for the chlorinated and non-chlorinated flours in each solvent, respectively. Such enhanced pasting characteristics (i.e. earlier occurrence of increased pasting viscosity at lower temperature) for the chlorinated flour constitute the major contributing factor to appropriate cake-baking performance. Pasting viscosities for the chlorinated flour in all the sugar solutions increased faster than those for the non-chlorinated flour, and peak viscosities for the former were significantly higher than those for the latter: 3194 vs. 2650 cP in water, 3929 vs. 2367 cP in

sucrose, 8753 vs. 6769 cP in fructose, 7638 vs. 5258 cP in glucose monohydrate, and 9477 vs. 8166 cP in xylose, for the chlorinated and non-chlorinated flours in each solvent, respectively. For both flour samples, the viscosity patterns for the flour slurries in water and xylose solution were similar, exhibiting the presence of peak viscosity and breakdown viscosity. In comparison, the viscosity patterns for the flour slurries in fructose, glucose, and sucrose were also similar, exhibiting only peak viscosity but not breakdown viscosity. Although the RVA behavior for the flour slurries in those sugar solutions was similar, pasting occurred earlier in fructose and glucose solutions than in sucrose solution, and their relative viscosities were much higher. Based on their RVA behavior, the four sugars could be categorized in three distinctive groups: 1) xylose, 2) fructose and glucose, and 3) sucrose.

Similarly to our results, Miller and Trimbo (1965) showed earlier viscosity increases (lower “apparent” temperature of initial gelatinization) during heating of layer cake batters or flour-water slurries containing glucose or invert sugar in place of sucrose. Bean and Yamazaki (1978) reported that amylograph viscosities emphasized the delaying effects of sucrose on gelatinization of starch and demonstrated that only first-stage swelling may occur in a 50% sucrose solution, before the medium boils. Such findings are applicable to layer-cake systems in which the formula level of sugar often equals that of water in the batter. Savage and Osman (1978) showed that increasing sugar concentrations delayed viscosity development for corn starch granules in the amylograph, with the 50% sugar concentrations also causing a pronounced increase in the temperature of maximum viscosity. They also reported that sugars at 50% concentration inhibited granular swelling, with various sugars yielding a greater variation in effects.

Effects of Different Sugars on Cake-Baking Performance

Top and side views of the cakes formulated with different sugars are shown in Fig. 3, and the baking results for the final cakes are presented in Table 3. Although the weight loss during baking of the cakes made with different sugars was not statistically significantly different, this cake baking with the chlorinated flour showed the following effects of 50.5 %S and 237.5 TS on HCC: Su FG > Su UF > F > G > X, and on HCE: Su UF \approx Su FG > F > G > X, but a different pattern for cake SF: Su FG \geq X > F = G = Su UF, because those baking responses reflected the complex behavior of vertical expansion followed by collapse or shrinkage. Specifically, the side views of the final cooled cakes in Fig. 3 suggested shrinkage of the center height, without collapse, for these %S = 50.5 systems. The different sugars, with their different particle size distributions, evidenced their different solubilities in water. The extents of swelling, dissolution, and viscosity development reflected the kinetic nature of the plasticizing diluent, in terms of its mobility and its mobilizing contribution to flour polymers in a sugar-water blend (Slade and Levine 1994). As reported previously (Kweon et al. 2009c), from our observations of the morphology and particle sizes for these sugars, sucrose FG crystals were much bigger than sucrose UF crystals, so their much slower dissolution was evidenced as expected. The fructose crystals were bigger than sucrose UF, but smaller than sucrose FG. The crystals of xylose and glucose monohydrate were similar and relatively smaller in size and shape.

The time-lapse photographs for the cakes during baking are shown in Fig. 4. From the cross-section photos of the cooled cakes at the bottom of Fig. 4, in particular, the internal crumb color for the xylose cake can be seen to have been quite yellow, very different from that for the other sugar cakes. While there have been no published reports on the crumb color for cakes baked with

xylose, Nishibori and Kawakishi (1992) reported that cookies formulated with pentoses, including xylose, were much more brown in baked color than those formulated with hexoses, including fructose and glucose, in part because of the higher amount of egg in their cookie formula, which enhanced color development via Maillard reactions. Similarly, our cake formula (Table 1) contained a relatively high amount of egg white powder, resulting in an analogous trend in baked color development. In the top views of the cakes shown in Fig. 3, the large differences in top-surface baked color are easy to see. If Maillard chemistry, with sugar type (reducing vs. non-reducing, aldose vs. ketose) as the only variable (Kunz et al. 2011), predicted cake top-surface color, resulting color from palest to darkest would have been in the order Su (non-reducing) << F (ketose) << G (aldose) < X (aldose). But it can also be assumed that cake color development depends in part on top-surface moisture content during baking. So taking into account the evident effect of sugar type on the small (but statistically insignificant) differences in weight loss during baking, shown in Table 3, for final moisture contents in the small range of 28.5-29.2% for these cakes, actually resulted in color from palest to darkest in the order Su FG < Su UF ~ G << F < X. Slade and Levine (1988) noted other significant differences among these sugars, in their physical properties related to molecular mobility. E.g., xylose is anomalous, because it has a T_m/T_g (crystalline melting temperature/glass transition temperature) ratio of 1.51, the highest-known value for simple sugars. In comparison, fructose is also anomalous, because it has a T_m/T_g ratio of 1.06, the lowest-known value for simple sugars, which is related to its unusually high solubility in water. In contrast, glucose and sucrose have T_m/T_g ratios of 1.42 and 1.43, respectively, which are typical of those for many other small sugars.

The measured cake center heights during baking, from the time-lapse photos in Fig. 4, are plotted in Fig. 5. In our previous report (Kweon et al. 2009c), time-lapse photographs for cookies during baking showed both lateral and vertical expansion, but those for cakes in this study (Fig. 4) showed only vertical expansion, because a baking pan was used instead of a baking sheet for cake baking, thus restricting lateral expansion. All the cakes showed much greater collapse during cooling after baking, rather than during baking, which resulted in smaller HCC values for the cooled cakes (Fig. 5). The cake made with xylose expanded quickly, due to enhanced initial starch pasting, and then set too early, due to egg white denaturation at a lower temperature (HCC increased faster than for glucose until minute 15, and then increased more slowly), prior to sufficient vertical expansion, resulting in the smallest cake volume. The changes in cake geometry during baking, as revealed in Figs. 4 and 5, can be linked to corresponding RVA behavior (Fig. 2): too-early starch pasting occurred in the xylose solution, and its viscosity pattern was different from those for fructose, glucose, and sucrose. Additionally, greater swelling of the flour arabinoxylans, due to xylose's significantly greater solvent compatibility with the xylan backbone (based on sucrose SRC 83.4% vs. xylose SRC 90.9% values for unchlorinated flour, as reported by Kweon et al. (2009c), and assuming a similar trend for chlorinated flour), contributed to the baking behavior for the cake made with xylose. The cake made with glucose expanded more slowly than for xylose, but ultimately expanded more and collapsed less. The cakes made with fructose or sucrose showed similar geometry changes, up to the 20 min baking time, owing to high solubilities and similar dissolution rates, but then for fructose after the 30 min baking time, the final cake geometry approached that for the glucose cake. As shown in Fig. 2, the RVA results for the flour slurries in glucose and fructose solutions were similar, so those two sugars were grouped together, which corresponded well with the results for their cake

geometries in Table 3. The changes in geometry for the cakes made with sucrose were different from those for the other sugars, again as supported by the RVA results. The effect of crystal size was not explored using RVA, because pre-dissolved sugar solutions were used, but it was explored using cake baking. As shown in Fig. 4, the two cakes made with different crystal sizes of sucrose exhibited very similar geometry changes during the first 25 min of baking. However, after 25 min, the cake made with Su UF showed no further vertical expansion, and then it collapsed. In contrast, the cake made with Su FG showed continued expansion until 30 min, and then less collapse, resulting in a significantly higher HCC. Among all the cakes, the one made with Su UF showed the greatest collapse after 30 min of baking, owing to more rapid dissolution, resulting in a smaller HCC than that for Su FG. Overall, starch pasting and egg-white setting occurred too early for the X, G, and F systems, but too late for Su UF, compared to the ideal cake-baking performance for Su FG. As reported previously (Kweon et al. 2009a) from our study to explore the effects of extent of chlorination, milling extraction rate, and particle size reduction of flour on flour functionality for baking, the present use of time-lapse photography and interpretation of the expansion profiles during baking for cakes formulated with this diagnostic series of sugars have been confirmed as a useful new approach for increased understanding about cake-baking functionality. This approach has made it possible to relate RVA behavior in diagnostic sugar solvents to cake-baking potential, toward the ultimate goal of guiding wheat breeding efforts to provide functional flours that can be used to bake high-ratio-type cakes with various types and levels of sugars.

CONCLUSIONS

The effects of the functionality of different sugars on high-ratio cake baking were explored, using a diagnostic series of small sugars: xylose, glucose, fructose, and sucrose. DSC results for both non-chlorinated and chlorinated flours showed that 50 w% sugar solutions retarded starch gelatinization in the order $X < F < G < Su$, but RVA results for the same flours showed enhanced starch pasting in the order $X > F > G > Su$. Cake baking with the chlorinated flour showed the effects of 50.5 %S and 237.5 TS on HCC: $Su FG > Su UF > F > G > X$, and on HCE: $Su UF \approx Su FG > F > G > X$, but a different pattern for cake SF: $Su FG \geq X > F = G = Su UF$, because of the complex behavior of vertical expansion, followed by collapse or shrinkage, with restricted lateral expansion. The impact of modulation of glutenin development and starch gelatinization/pasting on collapse was confirmed by the cake-baking performance with smaller (rapid dissolution) versus larger (delayed dissolution) particle sizes of sucrose. Time-lapse photography was used for interpretation of the expansion profiles during baking for cakes formulated with the diagnostic series of sugars, which led to a new and deeper understanding about cake-baking performance, and which made it possible to relate RVA behavior in diagnostic sugar solutions to the cake-baking potential of different sugars.

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FIGURE CAPTIONS

Figure 1. DSC thermograms for the non-chlorinated and chlorinated flours in various 50% (w/w) sugar solutions: flour:water or sugar solution = 1:1 w/w.

Figure 2. RVA results for the non-chlorinated and chlorinated flours in various 50% (w/w) sugar solutions: flour:water or sugar solution = 7:50 w/v.

Figure 3. Top and side views of cakes formulated with different sugars. Top view (top) and side view (bottom): upper row - left, sucrose UF; right, sucrose FG; bottom row - left, fructose; middle, glucose monohydrate; right, xylose.

Figure 4. Time-lapse photographs for cakes during baking for 35 min at 340°F: A, sucrose UF; B, sucrose FG; C, fructose; D, glucose monohydrate; E, xylose.

Figure 5. Height of cake center, measured from time-lapse photographs during cake baking for 35 min at 340°F: sucrose UF (-●-), sucrose FG (-○-), fructose (-▼-), glucose.H₂O (-△-), xylose (-■-).

Table 1. Ingredients and formula for high-ratio cake baking, according to AACCI 10-90.01 Method with minor modifications

Ingredient	Weight (g)
Flour	100 ^a
Sucrose	120.0
Nonfat dry milk	12
Egg white powder	9
NaCl	3
Sodium bicarbonate	1.95
Sodium acid pyrophosphate	0.29
Monocalcium phosphate	2.05
Shortening	37.5
Water ^b	117.5
Calculated %S ^c	50.5
Calculated TS ^d	237.5

^a Flour weight was on 14% moisture basis.

^b Water level was variable, $g = (100 - g \text{ flour}) + 117.5$.

^c %S calculated as sugar weight divided by the total solvent weight, based on 100 g of flour.

^d Total Solvent (TS) calculated as the sum of sugar weight and total formula water weight, based on 100 g of flour.

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Table 2. SRC results for non-chlorinated and chlorinated flour samples

Flour	pH	Moisture content (%)	SRC			
			Water	Lactic acid	Sodium carbonate	Sucrose
Non-chlorinated ^a	5.7a ^c	13.3a	44.2b	87.2a	57.1a	76.0b
Chlorinated ^b	4.6b	13.1a	49.3a	77.3b	58.0a	85.6a

^a indicated non-chlorinated patent flour with 55% milling yield.

^b indicated chlorinated patent flour with 55% milling yield.

^c Values followed by the same letter within each column are not significantly different at $p = 0.05$, t-test.

Table 3. Moisture loss during baking and final cake geometry, for cakes baked with different sugars

Sugar type	Weight loss (%)	HCC ^a (cm)	HCE ^a (cm)	SF ^a (HCC/HCE)
Sucrose UF	6.81a ^b	3.45b	2.66a	1.30b
Sucrose FG	6.53a	3.66a	2.66a	1.38a
Fructose	6.37a	3.28c	2.55b	1.29b
Glucose	6.17a	3.11d	2.42c	1.29b
Xylose	6.33a	2.82e	2.10d	1.35ab

^a HCC, height of cake center; HCE, height of cake edge; SF, shape factor.

^b Values followed by the same letter within each column are not significantly different at $p = 0.05$, Tukey-Kramer HSD test.

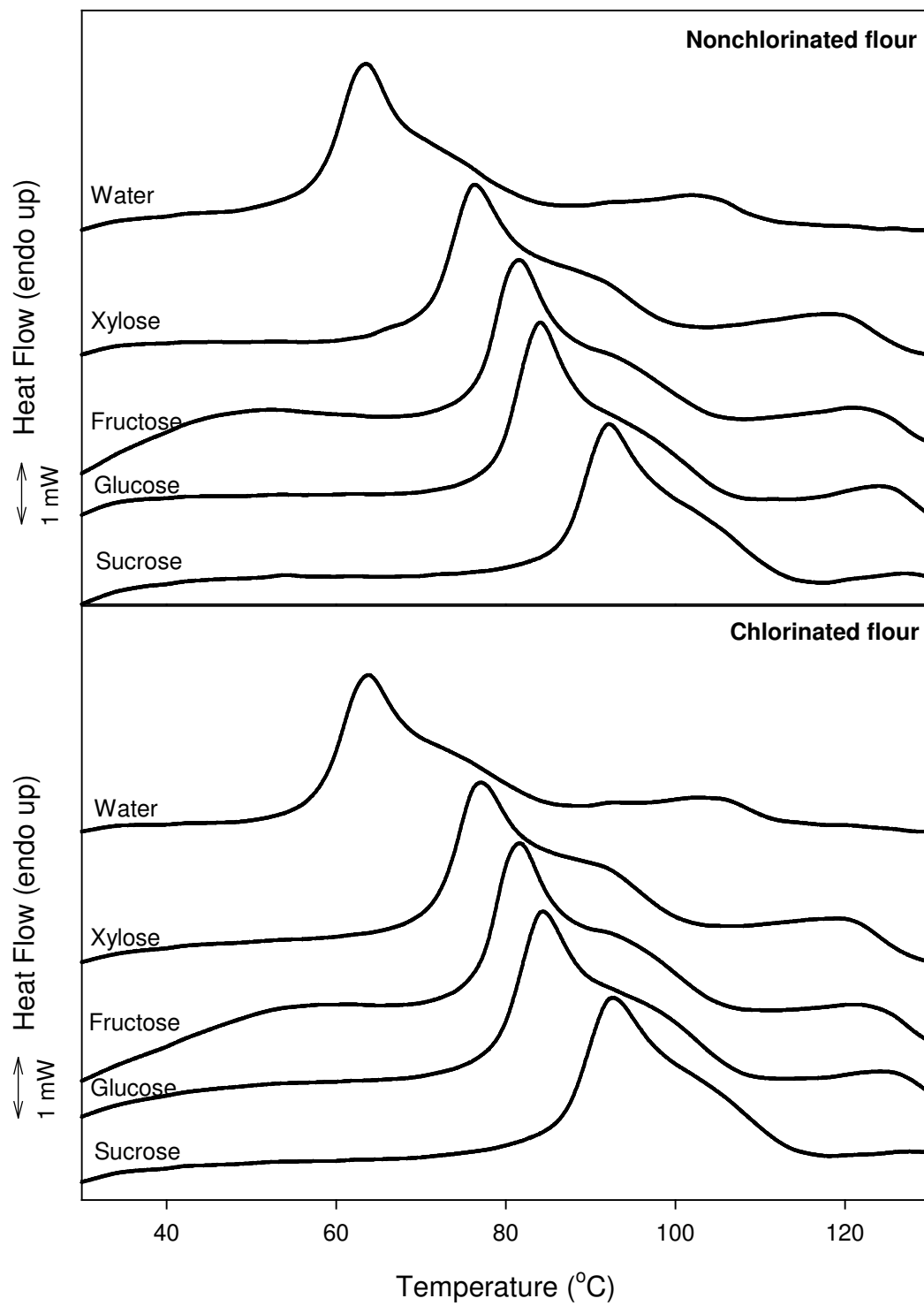


Fig. 1

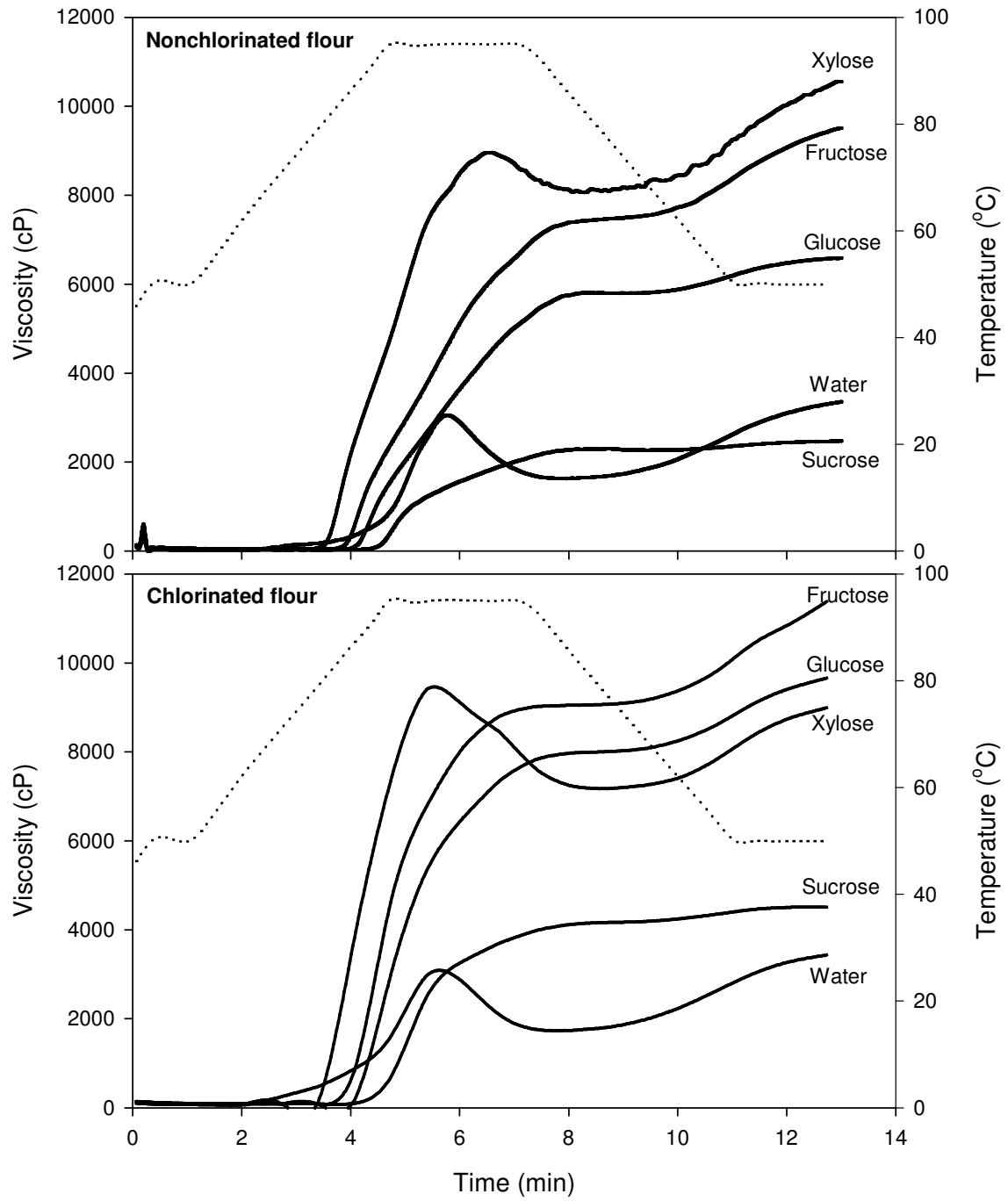


Fig. 2

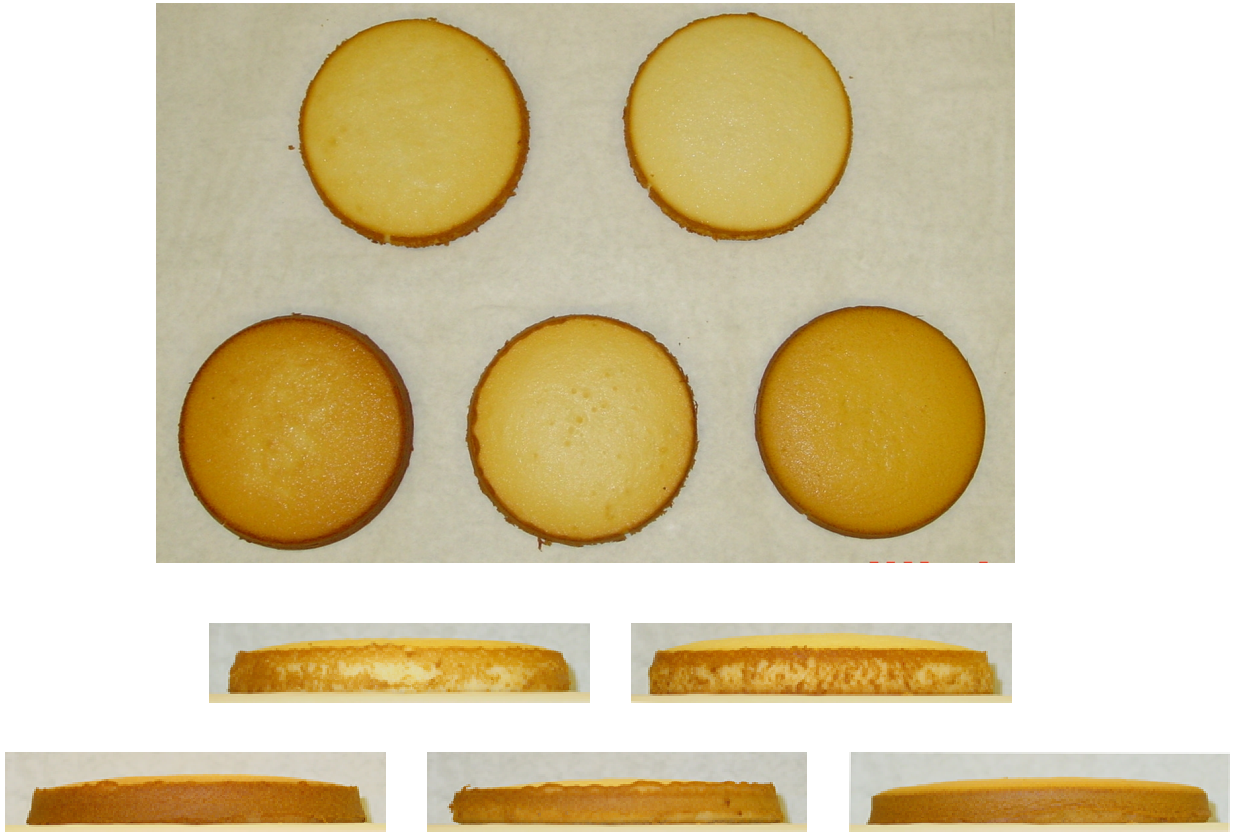


Fig. 3

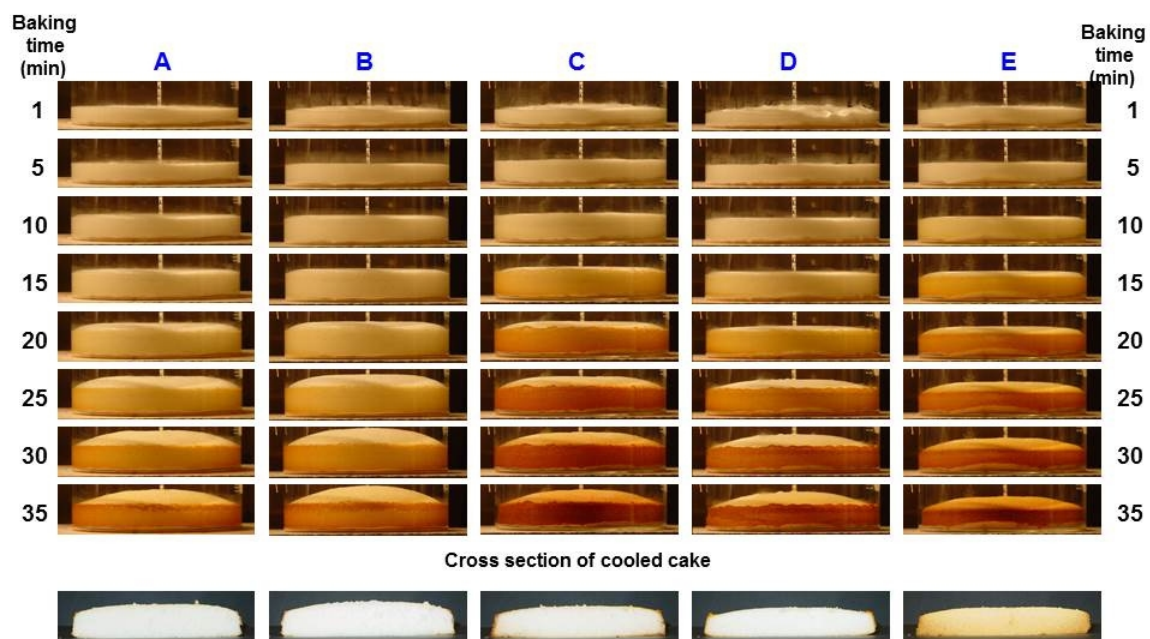


Fig. 4.

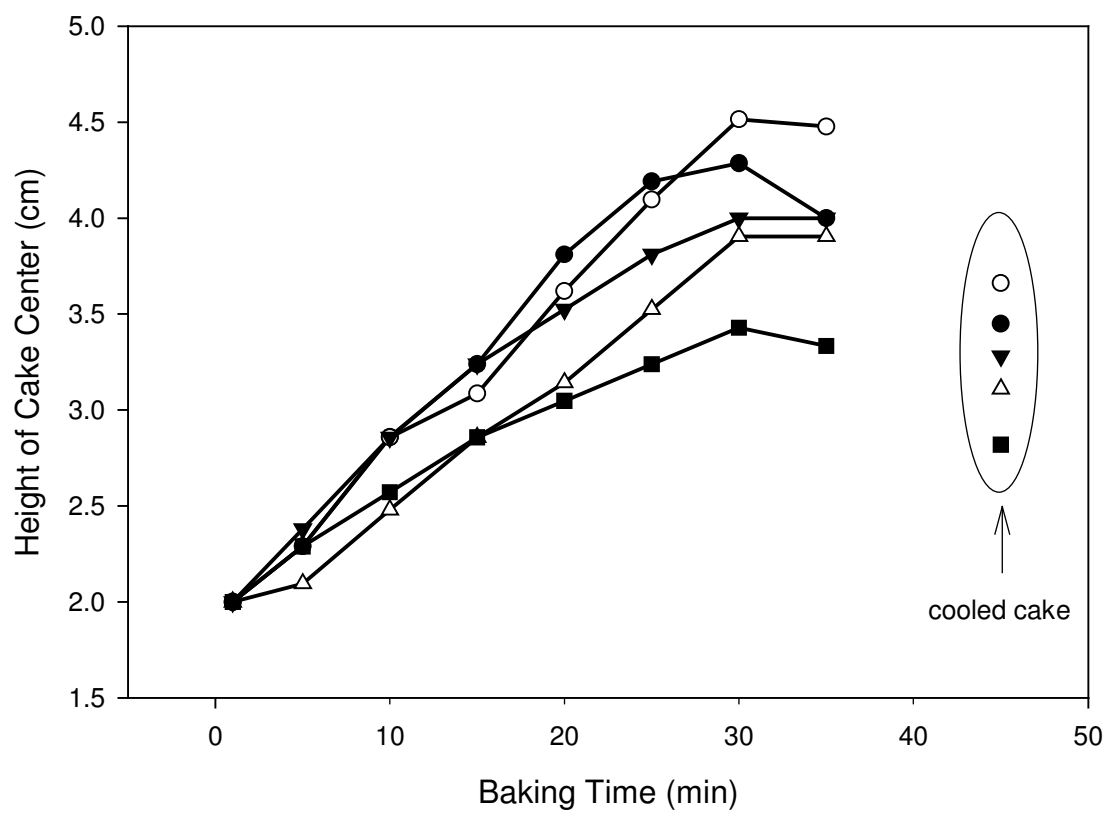


Fig. 5.