

## Sugar-Snap Cookie Dough Setting: The Impact of Sucrose on Gluten Functionality

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In sugar-snap cookie making, sucrose influences the physicochemical transformations of the flour components and is responsible for both cookie sweetness and texture. Sucrose, together with low moisture levels, raises the starch gelatinization temperature to such an extent that little if any of it gelatinizes during baking. However, there is no agreement on the effects that it has on gluten during cookie making. The present study revealed that increasing sucrose levels in the recipe increasingly delay or inhibit gluten cross-linking, as judged from the loss of sodium dodecyl sulfate-extractable protein. This causes cookies containing higher sucrose levels to set later and to have a larger diameter. Gluten entanglement and/or cross-linking result in resistance to collapse, at the same time, cause setting during baking and, hence, determine cookie diameter.

**KEYWORDS:** Sugar-snap cookie; sucrose; gluten; network; mobility; setting mechanism

### INTRODUCTION

Superior cookie flour generally results in cookies with large diameters (1). In Europe, wheat flour used for cookie making is generally inferior to that used in North America; i.e., it results in smaller cookies. This is because European cookie flour is generally not as “soft” as its North American counterpart. It has higher damaged starch levels and stronger gluten properties (2).

One possible way to overcome reduced oven spread is to increase the sugar level in the dough recipe. The influence of sugar on cookie dough spread has been explained in several ways. First of all, during baking, the progressive dissolution of sucrose yields an additional sucrose–water solvent phase. This has been estimated at ca. 0.66 cm<sup>3</sup> of solvent per gram of sucrose that dissolves per gram of water (2). Thus, higher sucrose levels increase the spread rate (3) and, hence, lead to a larger final cookie diameter (2).

However, sucrose not only contributes to solvent quantity, it also influences solvent quality (e.g., its concentration) (4, 5). Sucrose impacts the physicochemical phenomena that take place in the sugar–water medium during cookie making. It controls the glass transition temperature ( $T_g$ ) of macromolecules and, hence, their transformations (6). Sucrose containing solvent would plasticize gluten less than water alone (1, 7). As a consequence, higher sucrose levels (at constant water levels) cause the phenomena that induce cookie dough setting to take place at higher temperatures (3).

Further, in starch–water systems, sucrose raises the starch gelatinization temperature (8). In sugar-snap cookies with high sucrose levels, (almost) no starch gelatinizes during baking (2, 7).

In addition, during short dough making, such as in sugar-snap cookie making, sucrose delays or even inhibits gluten

development (4), because it competes with the flour for the recipe water (9, 10) such that proteins hydrate insufficiently to allow for the formation of a gluten network (11, 12). Already in 1958, Meiske et al. had stressed that, to prevent gluten from forming a network in dough, the dissolution of sucrose is a *conditio sine qua non*. Also, one could logically accept that increasing sucrose levels decreases gluten levels and that the resulting increasing amounts of dough sugar–water solvent (*cf. supra*) increasingly disperse the gluten polymers. This, hence, may well prevent the polymers from approaching one another, which otherwise would allow entanglement and cross-linking.

This brings us to the baking phase. Doescher et al. (13) postulated that, during cookie baking, as a result of the increase in temperature, gluten becomes mobile and forms a continuous matrix, which increases dough viscosity and, consequently, stops dough spread. According to Slade and Levine (7), gluten is the cookie spread controlling flour constituent during baking, because it can undergo its glass–rubber transition at temperatures and moisture contents relevant to cookie baking. However, according to Manley (14) and Chevallier et al. (15), no continuous protein network is formed during cookie baking.

Finally, Pareyt et al. (16), for a model cookie system using gluten–starch blends, observed a decrease in sodium dodecyl sulfate-extractable protein (SDSEP) levels during model cookie baking. They noticed that the decrease in SDSEP levels, which was related to gluten entanglement and/or cross-linking, went hand in hand with reduced cookie spread.

Despite the above, it is not clear whether or not proteins entangle and/or cross-link during cookie baking with different sucrose levels. Also, to the best of our knowledge, quantitative data describing the impact of sucrose (levels) on protein entanglement and/or cross-linking during sugar-snap cookie making are lacking. Against this background, we report here on the changes in SDSEP levels during baking of cookies with different sucrose levels and relate these to the end of cookie dough lateral

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**Table 1.** Sugar-Snap Cookie Dough Recipes

dough sugar (%)	flour (g)	sucrose (g)	margarine (g)	deionized water (g)	sodium bicarbonate (g)	dough moisture (%)	SWS (cm <sup>3</sup> ) <sup>a</sup>	sugar/(sugar + water)
Recipes with a Varying Sucrose Level but with a Constant Dough Moisture Level								
39.5	198.2	216.0	90.0	38.5	4.0	15.0	11.0	0.725
36.5	198.2	187.2	90.0	33.5	4.0	15.0	10.5	0.709
34.9	198.2	172.8	90.0	30.9	4.0	15.0	10.2	0.699
33.1	198.2	158.4	90.0	28.4	4.0	15.0	9.9	0.688
31.2 <sup>b,c</sup>	198.2	144.0	90.0	25.8	4.0	15.0	9.5	0.676
29.1	198.2	129.6	90.0	23.4	4.0	15.0	9.2	0.661
26.9	198.2	115.2	90.0	20.8	4.0	15.0	8.8	0.643
24.5	198.2	100.8	90.0	18.3	4.0	15.0	8.3	0.621
21.9	198.2	86.4	90.0	15.8	4.0	15.0	7.9	0.594
Recipes with a Varying Sucrose Level but with a Constant Sugar Solvent Volume								
28.7 <sup>c</sup>	198.2	129.6	88.0	32.0	4.0	16.6	9.5	0.634
26.1 <sup>c</sup>	198.2	115.2	86.2	38.5	4.0	18.3	9.5	0.587
23.4 <sup>c</sup>	198.2	100.8	84.1	44.5	4.0	20.1	9.5	0.538

<sup>a</sup>Sugar–water solvent volume = dough water level (g) + dough sucrose level (g) × 0.66 (2) based on average dough piece weight (26.6 g). <sup>b</sup>Control. <sup>c</sup>Equal sugar–water solvent volume.

expansion and final cookie height. Furthermore, the effect of the sugar–water solvent concentration on cookie spread behavior and final diameter was investigated. To that end, cookies with reduced sugar levels but with equal volumes of total calculated sugar–water solvent were baked while the dough spread behavior during baking was monitored. SDSEP levels were related to final cookie characteristics, i.e., dimensions (diameter and height), moisture level, and break strength.

## MATERIALS AND METHODS

**Materials.** Commercial cookie flour [moisture level, 13.2%; protein level ( $N \times 5.7$ ), 10.2%, dry base (db)] was from Meneba (Hasselt, Belgium). Moisture and protein contents were determined with American Association of Cereal Chemists (AACC) method 44-19 (17) and the Dumas method (16), respectively. Commercial sucrose (average crystal size of 470  $\mu\text{m}$ ) was from Iscal Sugar (Moerbeke-Waas, Belgium), and margarine (moisture content of 18.9%) was kindly provided by Vandemoortele (Izegem, Belgium). Sodium bicarbonate (BICAR) was from Solvay Chemicals International (Brussels, Belgium).

**Cookie Making.** Table 1 lists the recipes of cookie doughs with sucrose levels ranging from 21.9 to 39.5%. Cookie making was according to Pareyt et al. (3). For each recipe, at least three pans of five cookies were made per test. After baking (14 min, 185 °C) and cooling (30 min), cookie diameters were measured. Cookies with sucrose levels exceeding those of the control recipe were baked by gradually adding more sucrose in the ingredient bill while maintaining the dough moisture level constant (15.0%). For cookies with equal volumes of total sugar–water solvent, the volume loss by reducing the sucrose level was compensated by adding 0.66 cm<sup>3</sup> of water per gram of sucrose (2) removed. Therefore, while control dough contained 15.0% moisture, the dough with the lowest sugar level contained 20.1% moisture (Table 1).

**Time-Lapse Photography and Cookie Dough Sampling during Baking.** Time-lapse photography was conducted as described by Pareyt et al. (3). Also, separate batches of doughs were made for sampling during baking. One baking dough piece was removed every min (1–14 min time interval) from the oven and immediately submerged in liquid nitrogen to stop the baking process and, thus, the ongoing changes. The frozen dough pieces were then lyophilized, ground, and used for further analyses.

**Determination of Cookie Break Strength and Dough Elasticity.** Cookie break strength was determined as the peak force of the three-point-bending test as described earlier (3). Elasticity of dough disks (63.5 mm) was measured with a TAXT2i texture analyzer (Stable Micro Systems, Surrey, U.K.), equipped with a 5 kg load cell. Doughs were compressed 50% with a cylindrical probe (25 mm). Pretest, test, and post-test speeds were 2.0, 1.0, and 1.0 mm/s, respectively. The elasticity modulus  $E$  was calculated from the slope of the linear part of the curve, which plotted the

force as a function of the distance covered by the probe.

$$E = \frac{\alpha(1 - \nu^2)}{D}$$

In this formula,  $\nu$  represents the Poisson ratio [0.5 for cookie dough as proposed by Baltasvias et al. (18)],  $\alpha$  (N/mm) is the slope of the linear part of the curve, and  $D$  is the diameter (25 mm) of the probe (19).

**Analytical Procedures.** Defatting, differential scanning calorimetry (DSC), and determination of the SDSEP level with size-exclusion high-performance liquid chromatography (SE-HPLC) of dough and cookie samples were as described by Pareyt et al. (16). Both DSC and SE-HPLC analyses were conducted at least in triplicate and yielded standard deviations smaller than 2 and 5%, respectively.

**Statistical Analysis.** Pearson's correlation coefficients were calculated with the statistical analysis software 8.1 (SAS Institute, Cary, NC).

## RESULTS AND DISCUSSION

Table 2 lists elasticity and time-lapse parameters of cookie doughs containing different sucrose levels, as well as the dimensions, moisture levels, and break strengths of the resulting cookies. Because we did not exclude that starch would gelatinize during baking doughs containing reduced sugar levels and that, if so, this would affect dough setting, we conducted DSC of both doughs and cookies with different sucrose levels. No significant differences between onset ( $T_o$ ), peak ( $T_p$ ), and conclusion ( $T_c$ ) temperatures and enthalpy values of doughs and cookies were found (Table 3). Thus, under the baking conditions used, the starch did not gelatinize, even during baking of cookie dough with only 21.9% sucrose (and 15.0% moisture). Probably, dough water levels are still too low for starch to gelatinize.

**Dough Properties as a Function of Sugar Levels.** Dough elasticity increased linearly ( $R^2 = 0.87$ ) when sucrose levels were decreased (31.2–21.9% range). This can probably be related to more pronounced gluten development in the low-sucrose recipes. Gluten, when properly hydrated, as during bread making, forms viscoelastic dough. However, low water and high fat and sugar levels may counteract or even prevent dough development (20). From this, one can logically deduce that, when the sucrose level is reduced, gluten develops partly. Because no significant differences in SDSEP levels ( $73.1 \pm 2.6\%$ ) were noticed for the different doughs, this indicates that, provided differences in dough protein properties would exist for the different recipes, extraction with the buffer containing the powerful detergent SDS (21) would disrupt hydrogen bonds and reduce hydrophobic interactions (22) to

**Table 2.** Weight, Elasticity, Spread Rate, Set Time, and Degree of Collapse during Baking of Doughs with Different Sucrose Levels and Diameter, Height, Moisture Level, and Break Strength of Their Corresponding Cookies

dough sugar (%)	dough moisture (%)	dough piece weight (g)	dough elasticity (MPa)	spread rate (cm/min)	set time (min)	collapse (%)	cookie diameter (mm)	cookie height (mm)	cookie moisture (%)	break strength (N)
39.5	15.0	26.8 (0.5)	0.16 (0.01)	0.460 (0.005)	8.0 (0.2)	69.9 (0.1)	96.9	5.1	2.2	23.9
36.5	15.0	26.8 (0.4)	0.19 (0.01)	0.455 (0.025)	7.8 (0.5)	63.5 (0.1)	95.0	6.3	2.5	22.6
34.9	15.0	26.9 (0.3)	0.19 (0.01)	0.430 (0.110)	7.3 (0.4)	63.9 (0.1)	93.1	6.4	2.2	21.9
33.1	15.0	26.8 (0.5)	0.22 (0.01)	0.430 (0.080)	7.8 (0.6)	58.4 (0.1)	91.7	6.9	2.6	21.8
31.2 <sup>a,b,c</sup>	15.0	26.8 (0.7)	0.19 (0.02)	0.400 (0.005)	7.6 (0.1)	58.7 (0.2)	90.1	7.1	2.7	20.5
29.1 <sup>b</sup>	15.0	26.2 (0.5)	0.52 (0.03)	0.450 (0.025)	7.5 (0.2)	55.4 (1.3)	86.0	7.8	2.8	17.9
26.9 <sup>b</sup>	15.0	26.8 (0.7)	0.67 (0.04)	0.435 (0.045)	6.8 (0.6)	51.2 (0.1)	83.9	8.3	2.7	18.9
24.5 <sup>b</sup>	15.0	26.3 (0.5)	0.99 (0.05)	0.375 (0.005)	6.6 (0.1)	50.3 (2.1)	80.8	8.8	2.4	20.6
21.9 <sup>b</sup>	15.0	26.3 (0.4)	0.92 (0.10)	0.350 (0.005)	5.6 (0.2)	42.4 (1.7)	76.7	9.5	3.0	19.6
28.7 <sup>c</sup>	16.6	26.0 (0.5)	<sup>d</sup>	0.430 (0.010)	6.5 (0.1)	53.9 (0.1)	87.7	7.5	3.0	19.7
26.1 <sup>c</sup>	18.3	26.8 (0.3)	<sup>d</sup>	0.440 (0.005)	6.5 (0.2)	46.6 (1.6)	85.6	8.5	4.6	16.7
23.4 <sup>c</sup>	20.1	26.6 (0.7)	<sup>d</sup>	0.440 (0.015)	5.9 (0.1)	39.1 (1.8)	81.5	9.7	5.7	10.3

<sup>a</sup> Control. <sup>b</sup> Data from ref. 3. <sup>c</sup> Equal sugar solvent volume. <sup>d</sup> Not determined.

**Table 3.** Onset ( $T_0$ ), Peak ( $T_p$ ), Conclusion ( $T_c$ ) Temperatures ( $^{\circ}\text{C}$ ) and Gelatinization Enthalpies ( $\Delta H$ , J/g dm Starch) in Dough and Cookie Samples<sup>a</sup>

dough sugar level (%)	dough				cookie			
	$T_0$	$T_p$	$T_c$	$\Delta H$	$T_0$	$T_p$	$T_c$	$\Delta H$
31.2	62.8 (0.7)	68.6 (0.7)	78.5 (1.3)	11.4 (0.9)	62.0 (0.4)	68.2 (0.6)	77.1 (0.8)	12.3 (1.0)
29.1	61.7 (0.5)	67.7 (0.5)	76.6 (0.4)	11.3 (0.3)	62.8 (×)	68.9 (×)	77.5 (×)	10.7 (×)
26.9	61.3 (0.1)	67.7 (<0.1)	75.9 (1.1)	11.9 (0.8)	63.2 (1.1)	68.9 (0.6)	77.3 (0.7)	12.0 (1.1)
24.5	61.1 (0.3)	66.9 (0.3)	76.8 (0.5)	11.6 (0.5)	62.8 (0.2)	68.6 (<0.1)	76.6 (<0.1)	10.5 (0.1)
21.9	61.5 (0.2)	67.1 (0.2)	77.0 (0.2)	11.2 (0.3)	62.8 (0.3)	68.8 (0.4)	76.3 (0.2)	10.9 (0.2)

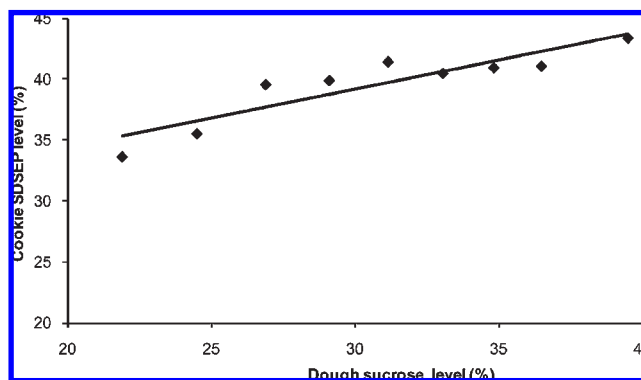
<sup>a</sup> Standard deviations are in parentheses.

an extent that masks these differences. Higher sucrose levels (>31.2% on a dough base) did not further impact dough elasticity. Probably, at the conditions used (15.0% moisture level and ca. 23  $^{\circ}\text{C}$  room temperature), the dough sugar–water phase was saturated, so that no additional sucrose dissolved in these doughs.

**Cookie Spread during Baking as a Function of Sugar Levels.** We earlier observed positive linear relations between the sugar level and both spread rate and set time (3). In the present case, the dough sucrose level was positively related to cookie diameter ( $R^2 = 0.98$ ), and negatively related to cookie height ( $R^2 = 0.99$ ) (Table 2). Adding extra sucrose to the control recipe increased dough spread rate and set time and, hence, increased and decreased cookie diameter and height, respectively (Table 2).

The contribution of sucrose to the spread rate has been explained in terms of volume creation by progressive sucrose dissolution during baking (2). From this, it can be concluded that the additional sucrose, which was added to the control dough recipe, also dissolved and, hence, probably also influenced the physicochemical phenomena taking place during baking.

**Cookie Setting during Baking as a Function of Sugar Levels.** As outlined in the Introduction, sucrose postpones the dough setting during cookie baking because it reduces protein entanglement and/or cross-linking. The present data (Figure 1), when compared to the dough SDSEP level ( $73.1 \pm 2.6\%$ , *cf. supra*), show that, for recipes containing as much as 39.5% sucrose, the SDSEP levels decreased during baking. A positive linear correlation ( $R^2 = 0.83$ ) was found between the dough sucrose level and cookie SDSEP levels (Figure 1). While the sugar levels clearly impact SDSEP levels, even for cookie doughs containing as high as 39.5% sucrose, protein aggregation because of cross-linking during baking is not prevented (cookie SDSEP level of 35.1 versus 73.1% for dough) but, instead, rather partly inhibited or delayed. Also, the higher sugar level cookies with larger diameter and less pronounced collapse had significantly higher SDSEP levels.

**Figure 1.** SDSEP levels of cookies with different sucrose levels.

The present data are in line with the observation by our group that aggregation during cookie baking reduces spread and that gluten is essential for cookie structure (16). It can be assumed that gluten forms a network, of which the viscosity is sufficient to stop spreading (23) and which provides the cookie structure. In that way, a pronounced network provides a strong structure and, hence, reduces collapse. They further lend support to the view by Slade and Levine (7) that, in response to the heat–moisture treatment during baking, gluten functions as either a thermoplastic or thermosetting amorphous polymer. According to these authors, the gluten thermosetting results in network features including resistance to macroscopic collapse and decreased lateral expansion.

During the first stages of baking (up to ca. 3–4 min), the SDSEP levels for different recipes increased slightly. This can probably be related to an increasing mobility, because of the fat melting and the sucrose dissolution, or, more likely, to a further plasticization of the gluten by the sucrose solution with increasing temperatures (Slade and Levine, personal communication). Then, at ca. 3–4 min, the SDSEP levels decreased, indicating the onset of gluten cross-linking. Table 4 shows that this occurred later

(4 versus 3 min) for recipes with higher sucrose levels (31.2 and 29.1%) than for those with lower sucrose levels (26.9 and 24.3%). Thus, when disregarding the probable outlier (4 min for dough with 21.9% sucrose), this would mean that higher sucrose levels delay the onset of protein cross-linking. However, taken together, the changes in SDSEP levels during baking (Figure 2) and the set times of the corresponding doughs (Table 2) show that loss of only part of the SDSEP suffices for the cookie doughs to set.

The SDSEP levels further decreased during the remainder of baking. For all doughs, this could be modeled by an exponential curve (fits had  $R^2 > 0.96$  for all recipes)

$$y = ae^{-bx}$$

in which  $y$  represents the SDSEP level,  $x$  is the time of baking (min), and the constants  $a$  and  $b$  represent the pre-exponential and exponential factor, respectively. In fact, the exponential factor  $b$  represents the rate of the decrease in SDSEP levels. A higher  $b$  value indicates a faster decrease and, hence, a more rapid loss of extractability. The  $b$  value varied between 0.114 and 0.083 for dough containing, respectively, 21.9 or 31.2% sucrose. A negative linear correlation ( $R^2 = 0.92$ ) was found between the  $b$  value and the dough sucrose level (Table 4), indicating that protein cross-linking is slower for the recipes containing higher sucrose levels. Expressed as a relative decrease per time unit, dough containing 31.2% sucrose showed a decrease of ca. 8.0%

**Table 4.** Onset of the Decrease in the SDSEP Level, Exponential Factor “ $b$ ” of the Model  $y = ae^{-bx}$  Predicting the Decrease in SDSEP, and Corresponding Decrease in SDSEP per Minute

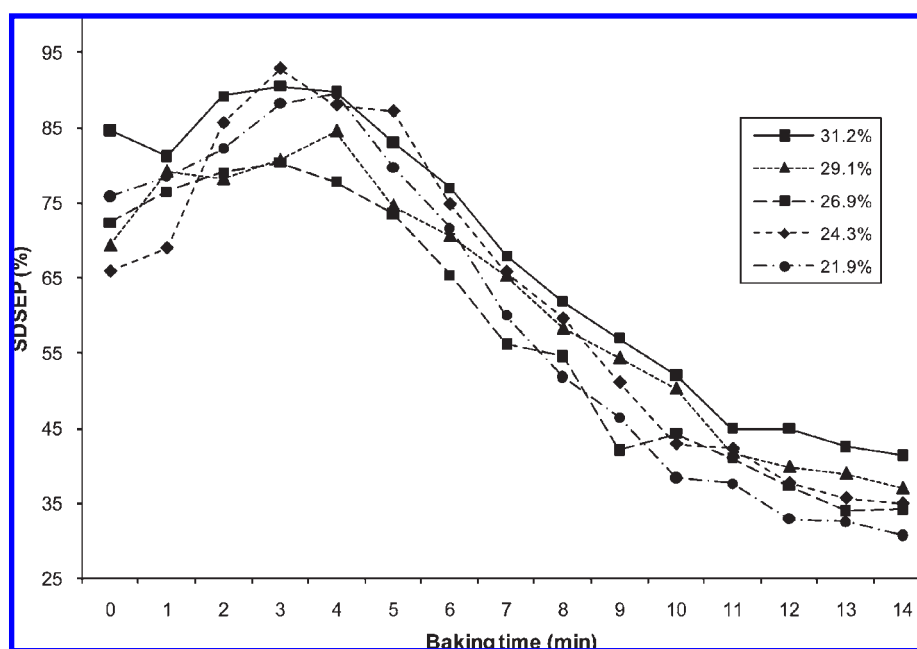
dough sugar level (%)	onset of decrease in SDSEP (min)	$b$ ( $\text{min}^{-1}$ )	decrease in SDSEP per min (%)
31.2	4	0.083	8.0
29.1	4	0.086	8.2
26.9	3	0.088	8.4
24.3	3	0.104	9.9
21.9	4	0.114	10.7

of SDSEP per minute, while this was ca. 10.7% for dough containing 21.9% sucrose. According to Slade and Levine (7), water–sucrose mixtures are less plasticizing than water alone and, thus, shift  $T_g$  to higher temperatures. Thus, by adding sugar, the temperature difference between the temperature (above  $T_g$ ) at which the reactions occur ( $T_{\text{rea}}$ ) and the  $T_g$  itself becomes smaller. It thus seems that the path from the initial to the final state is kinetically controlled (Slade and Levine, personal communication) and that the reaction rate increases with an increasing temperature difference ( $T_{\text{rea}} - T_g$ ).

Rates of physicochemical transformations, for practical time scales and concentrations relevant to food systems, are then related to the temperature difference  $T_{\text{rea}} - T_g$ , a non-equilibrium parameter, while extents may depend on both equilibrium and non-equilibrium factors. Because we only mentioned extents (i.e., non-ultimate states) observed as a result of baking, these may have been dictated by non-equilibrium, kinetic constraints (7).

Additionally, the negative linear correlation ( $R^2 = 0.88$ ) between the exponential factor and the set time shows that, when gluten cross-linked more readily, the setting was earlier. This would mean that the mobility of the system is the key to understanding the occurring transformations (24). Cookie dough setting, hence, is related to the mobility and availability of the plasticizing diluent (25), which is a (fat-emulsified) aqueous sucrose solution in this case. In that way and because the behavior of soft wheat flour dough plasticized by sugar–water solutions is critical to cookie baking performance (7), it was interesting to study the impact of different sucrose levels at a constant total sucrose–water solvent volume.

In this context, it was of primary importance to know whether or not all sucrose dissolved during baking. Therefore, we added extra sucrose to the control recipe. As already mentioned, the spread rate, set time, and cookie diameter further increased, which indicated that even the additional sucrose dissolved. From this, it was deduced that all sucrose dissolves in the control recipe chosen as a reference for reducing sucrose while keeping the total solvent volume constant. No starch gelatinization occurred in any of the samples (DSC results not shown). The set time (Table 2) decreased with decreasing sucrose levels and corresponding



**Figure 2.** SDSEP levels of cookie dough with different sucrose levels (indicated in the box) at different moments (0–14 min) during baking. The total moisture of unheated doughs was 15.0%.

increasing water levels. This went hand in hand with increased gluten cross-linking, as observed by lower SDSEP levels (29.9, 23.3, and 23.3% for doughs containing, respectively, 28.7, 26.1, and 23.4% sucrose). Furthermore, it seems that the decrease in set time was the dominant factor, because final cookie diameter also decreased, even with an increasing spread rate. These data, again, show the importance of the system mobility. As observed by Slade and Levine (7) during mixograph testing, the effect of sugar solution is not to decrease the “amount of water available” to hydrate the flour but, rather, to decrease the mobility of the system. Both higher spread rates and lower set times reflect an increased mobility. The latter indicates faster rates of gluten hydration and subsequent cross-linking as a result of the decreasing sucrose concentration. In agreement with the data outlined above, this then results in less collapse and higher cookies (Table 2). Also, the final cookie moisture level increased relatively more than the corresponding dough moisture levels, indicating that the network formation reduces moisture loss during baking (7). Probably, the observed decrease in cookie (vaporization) surface can be an alternative explanation. These data further clearly show that, because of the plasticization of the water present, the cookie break strength decreases (Table 2).

In conclusion, it seems that the system mobility is an important if not the most important parameter controlling the physico-chemical transformations during cookie baking. In general, higher sucrose levels restrict gluten mobility during cookie baking, while water has the opposite effect of plasticizing gluten. This was reflected in more pronounced gluten cross-linking with higher water levels and, conversely, less pronounced cross-linking with more sucrose.

#### ABBREVIATIONS USED

db, dry base; DSC, differential scanning calorimetry; SDS, sodium dodecyl sulfate; SDSEP, SDS-extractable protein; SE-HPLC, size-exclusion high-performance liquid chromatography;  $T_{\text{rea}}$ , reaction temperature;  $T_g$ , glass transition temperature.

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