Effect of Sugars and Flours on Cookie Spread Evaluated by Time-Lapse Photography[1]

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Cereal Chem. 64(3):163–167

ABSTRACT

Time-lapse photography was used to study the rate of expansion (spreading rate) and setting time during baking of cookie dough prepared with different sugars and flours. The type and the concentration of sugar used affected the spreading parameters. A combination of expansion rate and setting time determined cookie diameter. Among soft wheat flours, variation existed in set time and expansion rate. Rate of expansion was strongly correlated to cookie diameter (r = 0.90). In addition, set time significantly affected final cookie diameter (r = 0.50). Protein content was significantly correlated to expansion rate (r = −0.37) and to cookie diameter (r = −0.31). Alkaline water retention capacity of 45 soft wheat flours was lower than that usually reported but was significantly correlated to cookie diameter (r = −0.71).

Cookie spread or diameter is used as an indicator of cookie flour quality. Spreading characteristics appear to be controlled by a genetic property of the wheat and are modified somewhat by environmental conditions (Abboud et al 1985a). Hard wheat flours produce poor quality cookies (small in diameter). Among the soft wheats, wide variations in cookie quality exist depending on the cultivar (Yamazaki 1956).

The effects of ingredients and flour components on final cookie diameter have been studied extensively (Abboud et al 1985a; Clements and Donelson 1981; Cole et al 1960; Finney et al 1950b; Kissell et al 1971; Kissell et al 1973; Shanot 1981; Sollars 1956, 1959; Sollars and Bowie 1966; Thelen 1949; Tsen et al 1975; Yamazaki 1954, 1955, 1959a,b; Yamazaki and Donelson 1976; Yamazaki et al 1977), but few studies of what happens during the baking cycle have been reported. Abboud et al (1985b) used time-lapse photography to study the changes in cookie doughs during baking and found that the rate of spreading was greater for doughs made from good quality cookie flours. The expansion continued longer for doughs from soft wheat flour than for doughs from hard wheat flours. Hence, final cookie diameter was a result of spreading rate and setting time. Those results agree with the findings of Yamazaki (1956, 1959c).

The purpose of this study was to use time-lapse photography to determine the effect of sugar concentration and sugar type on the expansion rate and set time of cookie doughs. In addition, the effect of flour quality within various soft wheat cultivars on the expansion rate and set time of cookie doughs was determined.

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This manuscript was prepared for electronic processing.

MATERIALS AND METHODS

Materials

A commercial soft wheat cookie flour from Mennel Milling Company, Fostoria, OH, was used. It contained 8.0% protein, 13.4% moisture, and 0.41% ash. Forty-five other soft wheat flours were obtained from the Western Regional Wheat Quality Laboratories in Pullman, WA. Proximate analyses for those flours are given in Table I. A hard wheat flour from Ross Mills, Wichita, KS, containing 11.85% protein, 0.46% ash, and 13.5% moisture was used for certain baking trials. The sugar used was superfine pure cane sugar from Imperial Sugar Company, Sugar Land, TX. Anhydrous dextrose, D-fructose, and sodium chloride were reagent grade. Fine, powdered, grade one sodium bicarbonate (Arm and Hammer), from Church and Dwight Co., Princeton, NJ, and a commercial hydrogenated all-vegetable shortening (Crisco) from Procter & Gamble was used.

Cookie Baking

All cookies were baked according to micro method III (Finney et al 1950a) using soft wheat flour unless stated otherwise. A minimum of two trials was baked for each treatment.

Syrups were used in place of granular sucrose in some trials. When sucrose, glucose, or fructose syrups were used, the sodium chloride and ammonium bicarbonate were dissolved in the sugar solutions. The overall formula was not changed. In those trials, sugar solids were omitted from the cream. Cookies were baked with five percentages of sucrose: 0, 15, 30, 45, or 60% (control). Sucrose was used in granular form in the cream according to micro method III (Finey et al 1950a) or as a syrup with the leavening agents. At each sucrose level, enough water was used to maintain a constant volume of solution (water plus dissolved sucrose); this was calculated using the volume displacement factor for each sucrose concentration (Weast and Astle 1982).

Cookie doughs were prepared from a hard wheat flour and with creams containing 0, 15, 30, 45, 60, and 75% sucrose based on flour weight according to micro method III (Finney et al 1950a). The solution volume (water plus dissolved sucrose) was held constant across sucrose levels. The proper amount of leavening solution plus water was calculated using volume displacement factors (Weast and Astle 1982). The optimum amount of water at 60% sucrose was used as the standard in these calculations. For those cookies containing 75% sucrose, 0.40 g of NaCl and 0.3 g of NH_4HCO_3 solids were added to the cream. In those samples, the normal leavening solutions would not provide enough leavening in the volume to be used.

Cookies were also baked from 45 different soft wheat flours obtained from the Western Regional Wheat Quality Laboratories in Pullman, WA. The cookies were baked according to micro method III (Finney et al 1950a), except a constant absorption level of 25% was used for all flours.

TABLE I
Analytical Data for Flours Obtained from the Western Wheat Quality Laboratory[a]

Sample	Protein (%)	Moisture (%)	Ash (%)	AWRC[b] (%)
831189	6.7	12.3	0.42	57.25
831190	7.0	12.4	0.48	48.81
831192	6.1	12.3	0.40	53.88
831195	8.0	11.8	0.43	54.94
831200	7.4	12.1	0.43	53.54
831201	7.4	12.3	0.43	50.74
840891	9.0	12.6	0.47	55.12
840892	8.8	12.3	0.48	56.35
840893	8.6	12.3	0.45	61.34
840894	9.5	12.1	0.46	56.75
840895	8.2	12.2	0.44	56.43
840896	8.5	12.1	0.47	56.39
840897	8.5	12.2	0.42	54.71
840900	8.5	12.7	0.42	57.25
840901	9.3	12.5	0.42	53.53
840902	8.9	12.4	0.44	55.76
840903	7.8	12.2	0.46	52.92
840907	8.8	12.2	0.44	60.93
840908	9.7	12.1	0.44	54.88
840913	10.0	12.5	0.44	55.60
840916	7.9	12.3	0.42	58.19
840918	8.5	12.3	0.41	52.00
840922	11.3	11.7	0.35	53.67
840923	11.7	11.5	0.35	56.44
840926	10.8	11.8	0.36	56.60
840930	11.7	11.6	0.40	53.54
840932	8.8	11.9	0.43	55.88
840936	10.1	11.9	0.46	56.58
841007	10.9	11.8	0.45	55.78
841008	11.3	11.8	0.45	57.51
841020	11.0	11.5	0.44	54.10
841021	11.0	11.5	0.47	52.10
841026	11.8	11.5	0.47	56.99
841032	10.8	11.4	0.40	51.03
841033	11.3	11.4	0.40	52.07
841034	11.9	11.4	0.42	50.98
841043	11.6	11.3	0.48	51.16
841274	9.5	12.3	0.47	49.76
841275	9.3	12.1	0.41	46.29
841276	9.3	12.2	0.41	46.80
841277	7.9	12.3	0.36	48.04
841278	8.7	12.2	0.40	47.46
841279	7.9	12.3	0.41	52.89
841280	7.9	12.4	0.41	50.03
841281	8.6	12.2	0.41	48.47

[a] Mean of two determinations.
[b] AWRC = Alkaline water retention capacity; root mean square error = 0.105.

Water Loss During Baking

The amount of water lost during baking was determined for cookie doughs containing 0, 30, and 60% sucrose syrup, as well as the control (60% crystalline sucrose) cookie. A constant volume of solution (water plus dissolved sucrose) was maintained for each variable. The water loss during baking (1-min intervals) was measured according to the procedure described by Curley and Hoseney (1984). Water loss was taken as the change in total weight between the unbaked and baked cookies. Each sample was duplicated.

Alkaline Water Retention Capacity (AWRC)

AWRC was determined using AACC method 56-10 (AACC 1983), except that centrifuge tubes of 29 mm internal diameter and 164 mm long were used. Two determinations were made for each of the 45 flours.

Differential Scanning Calorimetry (DSC)

A Perkin-Elmer DSC-II equipped with an intercooler was used to determine the extent of starch gelatinization in cookie samples. Cookies were baked according to micro method III (Finney et al 1950a) using soft wheat flours as described previously. Immediately after cooling, the cookies were ground with a mortar and pestle. Approximately 4.5 mg of crumb was scaled into aluminum DSC sample pans. Sufficient water was added to make the moisture content 200% of the dry solids weight. All pans were sealed and scanned from 7 to 117°C at 10°C/min with a sensitivity of 0.5 mcal/sec.

In addition, cookie doughs were prepared as described above but omitting $NaHCO_3$ so that the hermetic seal of the calorimeter pan would not be disrupted. Approximately 3.5 mg of cookie dough was scaled into the aluminum sample pans and an appropriate amount of water was added to make the moisture content 200% of the dry solids weight. The pans were then sealed and scanned in the calorimeter as described above.

The area under the starch gelatinization curve was measured using a compensating polar planimeter from LASICO, Los Angeles, CA. An indium standard was used for enthalpy calculations. The enthalpy, ΔH, was calculated as:

$$\Delta H\ \text{sample} = \Delta H\ \text{indium} \cdot \frac{W\ \text{indium}}{W\ \text{sample}} \cdot \frac{A\ \text{sample}}{A\ \text{indium}} \cdot \frac{R\ \text{sample}}{R\ \text{indium}} \cdot \frac{S\ \text{indium}}{S\ \text{sample}}$$

where ΔH = heat of transition (cal/g), W = weight (mg), A = area under the curve, R = range sensitivity, and S = recorder chart speed (mm/min). Three independent trials were conducted for each sample. Means of the ΔH values were compared by the least significant difference (LSD) method.

Time-Lapse Photography

Time-lapse photographs were taken during baking using a modification of the procedure described by Yamazaki (1956). Cookie dough was deposited on a baking sheet with guidelines drawn 3.5 in. from the end of the sheet and down the center to form a cross so that the dough could be centered on the baking sheet. In addition, the cookie cutter was marked in fourths. The lines on the cutter were aligned with the marks on the baking sheet so that the cut cookie would be in the same location on every trial. A small steel bar of known dimension was placed beside the cookie on the guideline to serve as a reference so that the actual diameter of the cookie might be determined from the photographs. The baking sheet was placed on the oven rack with the cookie and steel bar towards the window. The edge of the cookie sheet was aligned with the edge of the oven rack. A camera mount was built on the oven door so that the focal length was constant. Vertical position of the camera was adjusted so that it was even with the baking rack. Photographs were taken at 60-sec intervals. The rate of dough expansion and the cookie set time (time at which dough stopped spreading) were determined by regression analysis (Milliken, Doescher, and Hoseney, *unpublished*). Two segmented lines were fitted to the data. The rate of dough expansion was the slope of the first line; the second line had a slope of zero and equalled the cookie diameter. Cookie set time was taken as the point where the two lines intersected (Abboud et al 1985b). Means were compared using LSD.

RESULTS AND DISCUSSION

Time-Lapse Photography

Time-lapse photography was used to study the expansion rate and setting time during baking of cookies prepared with different sugars. The control cookie set at the longest baking time (Table II). Although the cookie prepared from sucrose syrup set at an earlier time than the control, the diameter was not significantly smaller than that of the control. This was because it spread at a faster rate than the other cookies did. Cookies prepared with glucose syrup and fructose syrup set at significantly shorter times than the control did. The expansion rate for glucose and fructose syrup cookies was not significantly different from that for the control. Cookies prepared with fructose syrup and glucose syrup were significantly smaller than either the control or sucrose syrup cookies.

Cookies prepared with hard wheat flour set at significantly shorter times than the control (soft wheat) did (Table III). The expansion rate was slow for the cookies prepared with hard wheat flour. The combination of those two factors resulted in very small cookies. From these data, it appeared that both expansion rate and set time were important in determining cookie diameter.

TABLE II
Baking Data for Cookies Prepared with Different Sugars and Flours[a]

Sugar	Flour[b]	Rate of Expansion (cm/min)	Set Time (min)	Final Diameter (cm)
Granular sucrose	Soft	0.417 b	7.65 a	9.21 a
Sucrose syrup	Soft	0.475 a	6.85 b	9.06 a
Glucose syrup	Soft	0.428 b	5.59 cd	8.32 b
Fructose syrup	Soft	0.427 b	5.16 d	8.14 b
Granular sucrose	Hard	0.362 c	5.66 c	8.05 b

[a] Means within each column with different letters denote statistically significant differences at the 0.05 level.
[b] Commercial soft and hard wheat flours.

TABLE III
Effect of Sweetener on Enthalpy of Starch Gelatinization in Cookies from Soft Wheat Flour[a]

Sample	ΔH (cal/g)
Sucrose	
dough	0.107 a
crumb	0.094 a
Glucose	
dough	0.102 ab
crumb	0.079 c
Fructose	
dough	0.103 ab
crumb	0.068 d

[a] Means with different letters denote statistically significant differences at the 0.05 level.

Degree of Starch Gelatinization

Abboud and Hoseney (1984) showed that there was no starch gelatinization in cookies baked from sucrose doughs. To determine if the starch gelatinized in cookies prepared with sugar syrups, the enthalpy values (DSC) for sucrose, fructose, and glucose doughs were determined and found to be not significantly different (Table III). Those doughs contained no gelatinized starch because they had not been heated. The amount of starch gelatinized in the sucrose cookie was not different from that in the unbaked doughs, confirming the findings of Abboud and Hoseney (1984). However, with both glucose and fructose, the baked cookies had significantly lower ΔH values than the doughs. Thus, some of the starch was gelatinized during baking.

Abboud and Hoseney (1984) showed that there is no relationship between gelatinization temperature and setting time for cookies prepared from hard, soft, and club wheats. Although the lower ΔH value of glucose and fructose cookies in our study indicates some amount of starch gelatinization, it is questionable whether gelatinization contributes to the setting of the cookie dough. Perhaps the cookie sets via the temperature-mediated increase in viscosity suggested by Abboud et al (1985b), and then the starch gelatinizes. Savage and Osman (1978) have shown that monosaccharides do not increase starch gelatinization temperature as much as do disaccharides. In our study, the cookies containing glucose and fructose did show partial starch gelatinization, whereas the sucrose cookies did not.

Effect of Sucrose Concentration During Baking

Because both the type of sugar and the type of flour affected set time as well as the expansion rate, we wanted to determine how much variation in the baking parameters existed with changes in concentration of a single sugar. To study this, the amount of sucrose added to a cookie dough was varied from 0 to 60%. The total volume of solution in each dough was held constant by calculating the total volume of solution in a control cookie dough and then using it as the standard. If the formula water level had been held constant instead, both sucrose concentration and solution volume would have changed with the amount of sucrose used.

Abboud and Hoseney (1984) showed that approximately half of the sucrose dissolves during the mixing of the cookie dough and that the syrup contributes to dough viscosity and is related to the expansion rate of doughs during baking. When crystalline sucrose

TABLE IV
Effect of Sucrose Solids or Syrup Concentration on the Baking Properties of Commercial Soft Wheat Flour[a]

Amount of Sucrose (%)	Rate of Expansion (cm/min)	Set Time (min)	Final Diameter (cm)
Solids			
0	0.092 c	5.58 b	6.70 d
15	0.183 c	4.72 bc	7.00 d
30	0.408 ab	3.82 c	7.71 c
45	0.498 a	5.16 bc	8.64 b
60	0.427 ab	7.84 a	9.26 a
Syrup			
0	0.092 d	5.58 ab	6.70 e
15	0.209 c	4.72 bc	7.08 de
30	0.321 b	4.27 bc	7.48 cd
45	0.445 a	5.26 bc	8.42 b
60	0.404 ab	7.07 a	8.90 a

[a] Means within each column with different letters denote statistically significant differences at the 0.05 level.

was used in the present study, expansion rate was faster at 30, 45, and 60% than at 0 or 15% (Table IV). Cookies having 30% or more crystalline sucrose had the same expansion rate because the amount of dissolved sucrose was the same in each case. However, when the sucrose syrup replaced sucrose solids, the expansion rate increased with concentration (Table IV). Final diameter of the cookie increased as sucrose level increased in both cases. Set time followed a bell-shaped curve with 30% sucrose having the lowest set time.

TABLE V
Effect of Sucrose Concentration on Baking Properties of Commercial Hard Wheat Flour[a]

Amount of Sucrose (%)	Rate of Expansion (cm/min)	Set Time (min)	Final Diameter (cm)
0	0.115 c	4.50 b	6.58 c
15	0.199 bc	4.49 b	6.93 bc
30	0.241 b	4.34 bc	7.14 b
45	0.403 a	3.91 c	7.72 a
60	0.381 a	5.27 a	8.01 a
75	0.157 c	4.16 c	6.77 bc

[a] Means within each column with different letters denote statistically significant differences at the 0.05 level.

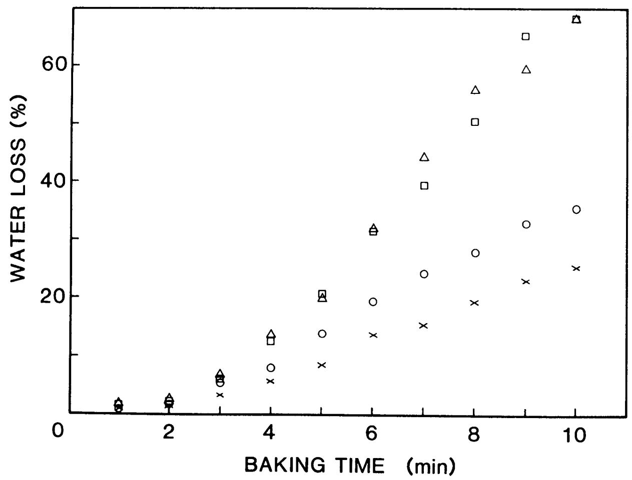

Fig. 1. Water loss versus baking time for cookies baked from commercial soft wheat flour with varied sucrose concentration: Δ = control (60% crystalline sucrose); □ = 60% sucrose syrup; o = 30% sucrose syrup; **X** = no sucrose.

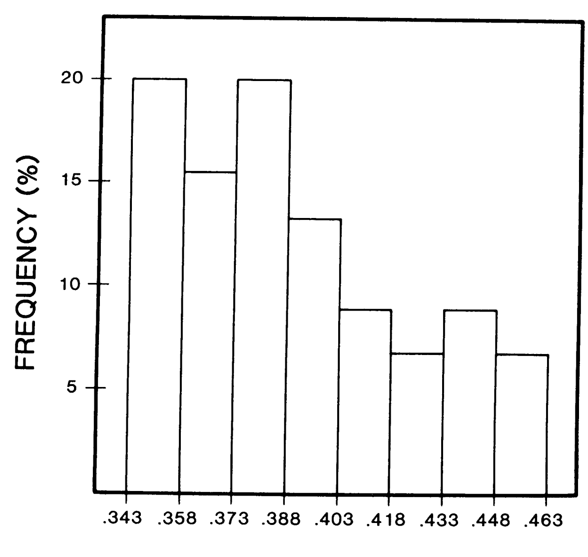

Fig. 2. Histogram of rate of expansion of cookie doughs from 45 soft wheat cultivars.

To evaluate the effect of sucrose concentration on cookies made with hard wheat flour, the crystalline sucrose level was varied from 0 to 75%. The expansion rate was the greatest at 45 and 60% sucrose (Table V). Both above and below those concentrations, the rate of dough expansion decreased. Set time was the longest at 60% sucrose. In general, final diameter of the cookie increased as sucrose concentration increased up to 60%, but at the 75% concentration, the final diameter was smaller than the control, the set time longer, and the rate of dough expansion slower. The volume of solution was held constant in this trial so that the available water in the cookie dough became limited at 75% sucrose. This gave a concentrated sugar solution whose viscosity was so high that the dough spread little. Because the solution volume was constant across sucrose concentrations, the osmotic pressure was changing. This could have affected the amount of water lost during baking.

Water loss measurements showed that both the control cookie dough and a dough containing 60% sucrose syrup lost approximately 68% of the total water in the dough (Fig. 1). Curley and Hoseney (1984) reported similar results. However, cookies prepared with 30% sucrose lost only 35% of their total water, and cookies made with no sucrose lost only about 25% of their total. Thus, at low sugar concentration more water is bound tightly by the flour, developing the gluten and limiting cookie spread.

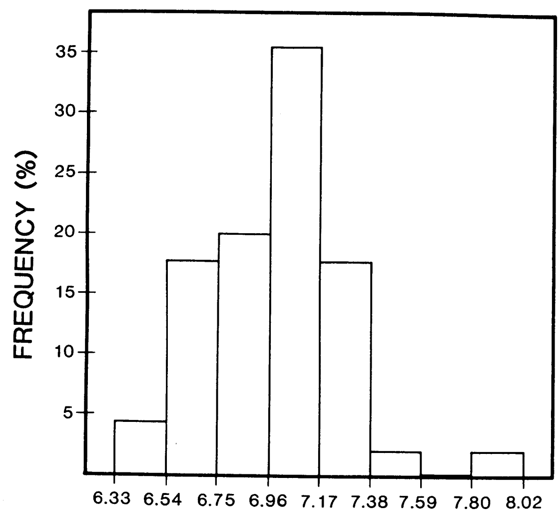

Fig. 3. Histogram of set time of cookie doughs from 45 soft wheat cultivars.

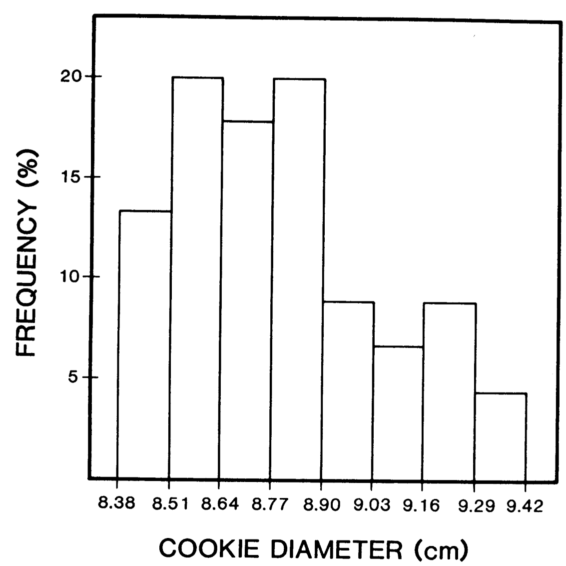

Fig. 4. Histogram of cookie diameters from 45 soft wheat cultivars.

TABLE VI
Correlation Coefficients for Baking Parameters from 45 Soft Wheat Flours[a]

	Rate of Expansion	Set Time	Cookie Diameter	Protein	AWRC[b]
Rate of expansion	···	0.11	0.90**	−0.37*	−0.61**
Set time		···	0.50**	0.11	−0.45*
Cookie diameter			···	−0.31*	−0.71**
Protein				···	0.04
AWRC[b]					···

[a]** Indicates significance at $P = 0.01$, * $P = 0.05$.
[b]AWRC = Alkaline water retention capacity.

Evaluation of Soft Wheat Flours

Variation among soft wheat flours was evaluated using time-lapse photography of cookie doughs during baking. Flours varied in protein content from 5.5 to 11.4%. Rate of expansion varied from 0.343 to 0.463 cm/min (Fig. 2) and was distributed over the entire range without clustering in one region (LSD = 0.066). Although set time varied from 6.33 to 8.02 min, most samples varied between 6.54 and 7.38 min (LSD = 0.76) (Fig. 3). Final cookie diameter was distributed over a wide range (Fig. 4) and was similar to the frequency distribution of the expansion rate.

The measured baking parameters (set time and expansion rate) were correlated to determine whether they were related. Rate of expansion and set time were not related (Table VI). As shown by the frequency distributions, the expansion rate of the cookie was strongly correlated to cookie diameter ($r = 0.90$). Cookie diameter was also significantly affected by set time ($r = 0.50$). Protein content was poorly but significantly correlated to expansion rate ($r = -0.37$) and to cookie diameter ($r = -0.31$). AWRC was lower than usually reported (Yamazaki 1953) but was significantly correlated to cookie diameter ($r = -0.71$).

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[Received May 8, 1986. Accepted November 24, 1986.]