Factors in Hard Wheat Flour Responsible for Reduced Cookie Spread[1]

R. A. MILLER[2,3] and R. C. HOSENEY[2,3]

Cereal Chem. 74(3):330–336

ABSTRACT

Time-lapse photography showed that, during baking, the diameter of sugar-snap cookies increased linearly then suddenly became fixed. Therefore, cookie diameter was a function of spread rate and set time. Cookies made with soft wheat flour were significantly larger in diameter (184 mm) than those made with hard wheat flour (161 mm). Cookies made with soft wheat flour set later (5.8 min) during baking than those made with hard wheat flour (5.1 min). The differences in set time within cookies made with various hard wheat flours or within cookies made with various soft wheat flours appeared to be affected by flour protein content. However, other factors also affected the difference in set time between cookies made with hard wheat and soft wheat flours. Cookies made with soft wheat flour spread at a faster rate (7.8 mm/min) than those made with hard wheat flour (4.6 mm/min). The level of soluble starch in the flour appeared to cause the difference in spread rate between cookies made with hard wheat and soft wheat flour. The higher level of soluble starch in hard wheat flour (0.352 ± 0.008%) than in soft wheat flour (0.152 ± 0.030%) increased dough viscosity, thus the spread rate was slower. However, soluble starch content did not explain the differences in spread rate within cookies made with various hard wheat flours or within cookies made with various soft wheat flours.

Quality testing of soft wheat flours essentially began in the 1950's (Finney et al 1950). A soft wheat variety is considered to have good quality when the flour yields cookies of large diameter with a uniform surface cracking pattern. Significant differences occur in the spread potential of different soft wheat varieties, however the reasons for the differences are not well understood. Many researchers have correlated chemical and physicochemical properties of the flour to the differences in cookie spread potential (Yamazaki 1953, 1954, 1959a; Cole et al 1960; Hayashi et al 1976; Gaines 1985; Abboud et al 1985a; Doescher et al 1987b; Kaldy et al 1991; Rogers et al 1993; Nemeth et al 1994). The technique of flour fractionation and reconstitution also has been used to determine the effect of individual flour components on cookie diameter (Yamazaki 1955, Sollars 1959, Cole et al 1960, Sollars and Bowie 1966, Donelson 1988). Unfortunately, none of these studies established sound relationships between flour properties and cookie diameter. This results in a lack of knowledge of what factors are responsible for cookie baking quality.

Sugar-snap cookies made from soft wheat flours are quite different from those made with hard wheat flours. Cookies made from soft wheat flour are thin, tender, and have a large diameter, whereas cookies made from hard wheat flour are thick, hard, and small in diameter. The reasons for these differences between the two types of flour are still unclear.

During baking, the diameter of sugar-snap cookies increases linearly then suddenly becomes fixed (Yamazaki 1959b, Abboud et al 1985b). Therefore, final cookie diameter is controlled by cookie spread rate and set time. Cookie spread rate appears to be controlled by dough viscosity (Yamazaki 1959b, Hoseney et al 1988, Hoseney and Rogers 1994). Cookies made with soft wheat flour spread at a faster rate during baking than cookies made with hard wheat flour (Abboud et al 1985b, Miller et al 1996). It is well known that flour with low hydration properties usually produce better cookies (Yamazaki 1962). However, the concentration of water-controlling components in the flour (i.e., pentosans, damaged starch, and protein) correlated poorly with cookie diameter (Yamazaki 1954, Cole et al 1960, Abboud et al 1985a, Kaldy et al 1991, Rogers et al 1993, Nemeth et al 1994). Therefore, some other, as yet unidentified, factor affects cookie spread rate.

Cookie set time appears to be caused by an apparent glass transition of the gluten protein in the flour (Doescher et al 1987a, Miller et al 1996). The gluten in sugar-snap cookie dough is not developed into a web during mixing; thus, the flour particles in the dough remain intact and discontinuous while the continuous phase is a sugar syrup. During baking, the gluten goes through an apparent glass transition, thereby gaining mobility that allows it to interact and form a web. The viscosity of the continuous gluten web is sufficient to stop the flow of the cookie dough (Miller et al 1996). The apparent glass transition temperature (T_g) of cookies made with hard wheat flour is lower than that of cookies made with soft wheat flour (Doescher et al 1987a, Miller et al 1996). However, the reason for the difference was not clear (Miller et al 1996).

The objective of this study was to determine what factors in hard wheat flour are responsible for reduced cookie spread and whether those same factors affect differences in baking quality within soft wheat flours and within hard wheat flours.

MATERIALS AND METHODS

Cookie Ingredients

A commercially milled, untreated, soft wheat flour containing 0.43% ash and 7.6% protein (14% mb) was obtained from Mennel Milling Co. (Fostoria, OH). A commercially milled, untreated, hard wheat flour obtained from Cargill (Wichita, KS) contained 0.50% ash and 10.8% protein (14% mb). Composite hard wheat patent flours from different regions were provided by the Kansas State University Wheat Quality Lab (Manhattan, KS). Samples of the pure soft wheat cultivars Argee, Becker, Caldwell, Cardinal, Daws, Gore, Lewjaw, and Stephens were provided by the USDA Soft Wheat Lab (Wooster, OH) and the Western Wheat Quality Lab (Pullman, WA). Samples of the pure hard wheat cultivars Larned and Ponderosa were obtained from certified seed growers in Kansas. A sample of the pure hard wheat cultivar Glenlea was donated by the University of Manitoba (Winnipeg, Canada). All of the pure cultivars were milled into straight-grade flour.

Superfine sucrose was obtained from C&H (Concord, CA). Nonfat dried milk was supplied by American Ingredients (Kansas City, KS). Crisco, a commercial, hydrogenated, all-vegetable shortening containing mono- and diglycerides manufactured by Proctor and Gamble (Cincinnati, OH), was used. Sodium bicarbonate, sodium chloride, and ammonium chloride were reagent grade.

[1]Contribution No. 96-494-J, from the Kansas Agricultural Experiment Station.
[2]Research associate and professor, respectively, Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506.
[3]Present address: R&R Research Services, 8831 Quail Lane, Manhattan, KS 66502. Corresponding author. E-mail: r_and_r@kansas.net

Publication no. C-1997-0410-06R.
© 1997 by the American Association of Cereal Chemists, Inc.

Cookie Baking

Cookie doughs were prepared using AACC Method 10-52 (AACC 1995). Preliminary studies showed that altering dough water absorption did not affect final cookie diameter (*data not shown*). Therefore, water absorption was held constant at 25% (fwb, v/w) for all formulations. The cookies were baked for 10 min at 205°C in a reel oven (National Mfg., Lincoln, NE). The diameter of two cookies was measured after the cookies had cooled completely. The average of three measurements is reported. A minimum of two replicates was baked for each treatment.

Time-Lapse Photographs

Photographs of a single cookie were taken during baking with a camera mounted to the oven door. Guidelines were drawn 8.9 cm from one end of a baking sheet (parallel to the edge) and down the center to form a cross. Cookie dough was placed on the sheet, rolled, and cut so that the cookie was centered over the cross to assure that the cut cookie was in the same position in every trial. A small metal bar of known dimension was placed at a marked position on the guideline beside the cookie so the actual diameter of the cookie could be determined from the photographs. The baking sheet was placed on a stationary shelf in the oven. The shelf was adjusted so that the camera was at the same level as the cookie. Photographs were taken of the cookie at 30-sec intervals during baking. Cookie diameter was measured directly from the photographs and plotted as a function of baking time to determine set time and spread rate. Set time was the time at which the cookie stopped spreading. Spread rate was determined by measuring the slope of the line between the time when the cookie began to spread (~1 min) and the set time. A minimum of two replicates was baked for each treatment.

Thermo Mechanical Analyzer Method

A Thermo Mechanical Analyzer (TMA) (Rheometric Scientific, Piscataway, NJ) was used to determine the apparent glass transition temperature (T_g) of cookie dough as described by Miller et al (1996). Cookie doughs were prepared for TMA analysis using AACC Method 10-52 (AACC 1995) with two modifications. Chemical leavening agents were omitted, and the sodium chloride level was increased to 0.4 g per dough (40 g flour). In preliminary trials, expansion of the cookie dough by the leavening agents made measurement of the apparent T_g impossible. Preliminary studies showed that adjusting the pH of the unleavened cookie dough to that of leavened cookie dough with NaOH did not significantly affect cookie diameter or T_g (*data not shown*). The sodium chloride level was increased to compensate for salt ordinarily produced in the chemical leavening reaction.

A sample of cookie dough ~2 mm thick was placed in the TMA, and a thin glass plate was placed on top of the dough. The glass plate prevented direct contact between the dough and the TMA probe and eliminated penetration by the probe through the dough as it softened during testing. All samples were heated from 25 to 100°C at a rate of 1°C/min. The temperature at which the dimension of the sample began to increase rapidly was taken as the apparent T_g.

Effect of Sucrose Level

Sucrose level was varied to determine its effect on cookie set time, apparent T_g, and spread rate. Sucrose levels were 60 (control), 50, 40, or 30% (fwb, w/w). Water absorption was constant at 25% (fwb, v/w).

Water Activity

Water activity (a_w, %rh/100) of cookie doughs was measured with a water activity meter (CX-2, Decagon Devices, Inc., Pullman, WA). Cookie doughs were prepared according to AACC Method 10-52 (AACC 1995), except that the cream, water, and leavening solutions were mixed for 10 min before addition of the flour. The longer mixing time produced a more uniform cream and improved the reproducibility of the a_w measurements. Cookie dough was pressed lightly into the sample cup. The water activity meter was calibrated with saturated salt solutions before testing. A minimum of three doughs was measured for each treatment.

Flour Fractionation

Flour-water doughs (60% absorption) were mixed to optimum development. Gluten was separated by hand-washing in distilled water then lyophilized. It is presumed that the bulk of the flour lipids were bound to the gluten during separation. The wash water was centrifuged (Damon/IEC Division, Needham Hts., MA) at 1,000 × *g* for 15 min. The supernatant was shell-frozen and lyophilized to recover the water soluble (WS) fraction that contained soluble protein, soluble starch, and soluble pentosans. The starch fraction, consisting of both the prime and tailing starch, was lyophilized then rehydrated in a humidified cabinet to a moisture content of ~13% before reconstitution. The prime starch fraction consisted of the large, undamaged granules. The tailing fraction contained the small granules, damaged granules, and insoluble pentosans.

Flour Reconstitution

Original flour compositions were determined by separating and lyophilizing a known weight of flour, weighing the dried components, determining the moisture content of the dried components, and converting the weight to a dry weight basis (dwb). The recovery of fractions from the soft wheat flour was ~13% gluten, 73% starch, and 3% WS (dwb). The hard-wheat flour fractions were ~11% gluten, 70% starch, and 5% WS (dwb). Reconstituted flours containing at least two soft wheat fractions were made with the soft-wheat flour recovery ratios, and reconstituted flours containing at least two hard wheat fractions were made with the hard-wheat flour recovery ratios. For reconstitution, the appropriate fractions were weighed and mixed with 74% water (dwb) to optimum dough development as described by Yamazaki (1955). Mixing times were ~1 min for soft-wheat reconstituted flours and ~2 min for hard-wheat reconstituted flours. The reconstituted doughs were lyophilized and then ground into flour with a laboratory Wiley mill (Arthur Thomas Co., Philadelphia, PA) through a number 40 sieve. Flours were rehydrated in a humidified cabinet to ~13% moisture before baking.

Total reconstitutes containing all fractions from the same flour were made as controls. These were labeled as hard reconstituted flour and soft reconstituted flour. The reconstituted flour treatments consisted of switching each major fraction (gluten, starch, or WS) of one flour (hard or soft) into the other flour. Reconstituted flour combinations are listed in Table I. Each reconstituted flour combination was made at least in duplicate.

Soluble Starch Measurement

Soluble starch was measured using the Total Starch Assay Procedure (amyloglucosidase/α-amylase method) by Megazyme (Wicklow, Ireland), modified slightly to measure soluble starch

TABLE I
Reconstituted Flour Combinations[a]

	Flour Type		
Sample Number	Gluten	Starch	Water Soluble
1	Soft	Soft	Soft
2	Hard	Soft	Soft
3	Soft	Hard	Soft
4	Soft	Soft	Hard
5	Hard	Hard	Hard
6	Soft	Hard	Hard
7	Hard	Soft	Hard
8	Hard	Hard	Soft

[a] All combinations were made at least in duplicate and in random order.

rather than total starch. Flour or gluten was slurried in distilled water (1:10, w/v) for 2 min. The slurry then was centrifuged at 1,000 × *g* for 15 min. The insoluble fraction was discarded. The supernatant, which contained the soluble starch, was collected and used for starch measurement as described in the method.

Soluble Starch Removal

Soluble starch was removed from the water soluble (WS) and gluten fractions from *Aspergillus oryzae* (Type X-A Fungal Crude Alpha-Amylase, EC 3.2.1.1, Sigma Chemical Co., St. Louis, MO). WS were separated from 800 g of flour and used as is. Dry gluten (100 g) was slurried with distilled water (1:10, w/v) in an Osterizer blender on low speed for 3 min. The pH of both the WS and the gluten slurry was adjusted to 6.9 (enzyme optimum) with sodium bicarbonate. α-Amylase (37 units) was added, and the solutions were stirred with a magnetic stirrer for 2 hr at room temperature. After treatment, the WS were boiled to inactivate the enzyme, then lyophilized. Preliminary studies showed that adjusting the pH and boiling the WS did not alter their cookie baking properties (*data not shown*). The enzyme in the gluten slurry could not be denatured by boiling without affecting the properties of the gluten. Therefore, the gluten slurry was centrifuged at 1,000 × *g* for 15 min to remove the enzyme. The supernatant, containing the enzyme, was discarded, and the recovered gluten was washed with distilled water, then lyophilized. The α-amylase-treated WS and gluten were used to prepare reconstituted flours as described above with the recovery ratios for hard wheat flour.

Data Analysis

Data were evaluated by analysis of variance (ANOVA), least significant difference, and regression analysis. The Statistical Analysis System (SAS 1990) was used for data analysis.

RESULTS AND DISCUSSION

Cookies made with soft wheat flour had a larger final diameter (184 mm) than cookies baked with hard wheat flour (161 mm). Cookies made with soft wheat flour spread at a faster rate and set (stopped spreading) at a later time during baking than cookies made with hard wheat flour (Fig. 1). Therefore, final cookie diameter was a function of spread rate and set time. It should be noted that multiplying spread rate by set time does not equal the measured diameter of the actual cookies. This is because the spread rate was calculated to be a constant rate when, in fact, it deviates at certain points (i.e., at the start of heating and as the set time was approached).

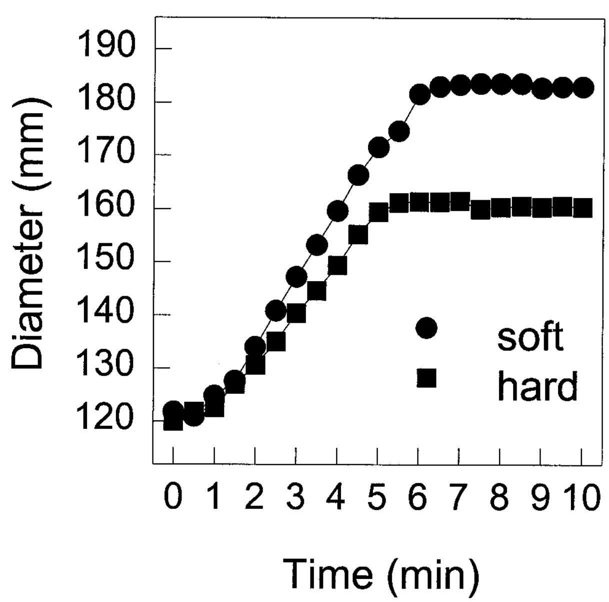

Fig. 1. Changes in cookie diameter during baking of cookie doughs made with soft wheat (●) and hard wheat (■) flours.

Cookie Set Time

As shown previously with the same flour samples (Miller et al 1996), cookie set times were 5.8 min and 5.1 min for cookie doughs made with soft wheat and hard wheat flours, respectively. The T_g of cookie doughs made with soft wheat and hard wheat flours were 78 and 71°C, respectively. Thus, both set time and apparent T_g of cookies baked with hard wheat flour were lower than those of cookies baked with soft wheat flour. This was consistent with previous studies (Abboud et al 1985a, Doescher et al 1987a).

At 13% moisture, the apparent T_g of soft wheat and hard wheat flours were identical (Mathew and Hoseney 1994; Miller et al 1996). Therefore, the difference in the apparent T_g of cookie doughs made with soft wheat and hard wheat flours was not caused by a difference in the apparent T_g of the two flours, but by some other factor.

Effect of Sucrose Level on Set Time

Sucrose is a major ingredient in the cookie system that is known to affect cookie diameter (Finney et al 1950, Doescher et al 1987b). Increasing the sucrose in the formula increased both apparent T_g and set time of cookie doughs made with soft wheat or hard wheat flour (Table II). Thus, larger quantities of sucrose delayed cookie set time (Miller et al 1996). At all sucrose levels, cookie doughs made with hard wheat flour set earlier and had a lower apparent T_g than cookie doughs made with soft wheat flour. Set time correlated highly with apparent T_g (r = 0.971 for soft wheat flour and r = 0.989 for hard wheat flour) (Miller et al 1996).

Roos (1987) showed that T_g was a function of a_w at constant temperature. Sucrose is known to affect a_w, therefore, sucrose may affect the apparent T_g by controlling the a_w of the cookie dough. Apparent T_g and a_w for cookie doughs made with hard wheat and soft wheat flour were highly correlated (r = –0.933 and r = –0.964, respectively). However, at the same sucrose concentration, the a_w of cookie doughs made with hard wheat flour was significantly lower than that of cookie doughs made with soft wheat flour (Table II). This is presumably because the hard wheat flour contained more damaged starch which absorbs large quantities of water. The lower a_w in cookie doughs made with hard wheat flour should result in a higher apparent T_g. It does not. Therefore, a_w does not explain the difference in apparent T_g of cookie doughs made with hard wheat and soft wheat flours.

Sucrose can act as a plasticizer, but it is much less effective than water because of its larger molecular weight (Eisenberg 1984, Kalichevsky et al 1992, Slade and Levine 1995). Antiplasticizing agents are known to increase T_g. Therefore, sucrose may have its effect by acting as an antiplasticizer (compared to the effect of water). Although apparent T_g of cookie doughs made

TABLE II
Effect of Sucrose Level on Set Time and Water Activity of Cookie Doughs Made with Soft Wheat and Hard Wheat Flours[a]

Flour Type	Sucrose (%)[b]	Set Time (min)	Water Activity
Soft	60	5.00a	0.771de
Soft	50	4.75ab	0.767e
Soft	40	4.25c	0.786c
Soft	30	3.50d	0.822a
Hard	60	4.75ab	0.759f
Hard	50	4.50bc	0.755f
Hard	40	3.50d	0.776d
Hard	30	3.00e	0.812b

[a] Means in a column followed by different letters are significantly different ($P < 0.05$).
[b] Flour weight basis.

with both hard wheat and soft wheat flour increased as sucrose level increased, the apparent T_g of cookie doughs made with soft wheat flour increased at a faster rate (Fig. 2). The soft wheat flour had a lower protein content than the hard wheat flour (7.6 vs. 10.8%). Therefore, the ratio of sucrose to protein was higher in cookie doughs made with soft wheat flour than in cookie doughs made with hard wheat flour. The difference in protein content was removed by dividing the sucrose level (grams) in the formula by the amount of protein (grams) in the flour. The apparent T_g of the cookie doughs made with hard wheat and soft wheat flours then could be compared on a constant sucrose-protein basis. When corrected for protein content, the apparent T_g of cookie doughs made with hard wheat and soft wheat flours increased at the same rate when the sucrose level was increased (Fig. 3). Apparent T_g and ratio of sucrose to protein were highly correlated ($r = 0.989$). Thus, the difference in apparent T_g between cookie doughs made with hard wheat and soft wheat flours appeared to be caused by a difference in the sucrose-to-protein ratio. Because cookie doughs made with soft wheat flour contained more sucrose per unit of protein, the apparent T_g was raised to a higher temperature than that of cookie doughs made with hard wheat flour. Therefore, the difference in set time between cookie doughs made with hard wheat and soft wheat flours appeared to be affected by a difference in flour protein content.

Effect of Protein Content on Set Time

The set times of several soft wheat and hard wheat flours of different protein contents were measured to determine whether protein content was the only factor controlling cookie set time. Although there was reasonable correlation between protein content and set time within the soft wheat flours ($r = -0.601$) and within the hard wheat flours ($r = -0.690$), the soft wheat and hard wheat flours formed two separate populations (Fig. 4). This indicated that some factor in addition to protein content was affecting cookie set time.

Cookie Spread Rate

Sucrose level had a different effect on the spread rate of cookie doughs made with hard wheat and soft wheat flours. At all sucrose concentrations, cookie doughs prepared with soft wheat flour spread at a faster rate than those prepared with hard wheat flour (Table III). As sucrose concentration was increased, the spread rate of cookie doughs made with soft wheat flour also increased. However, increasing the sucrose concentration of cookie doughs made with hard wheat flour did not affect the spread rate.

Effect of Flour Fractions

A fractionation and reconstitution scheme (Table I) was used to determine the effect of each flour fraction on the diameter and spread rate of cookies made with hard wheat and soft wheat flours. Cookies made from reconstituted flours containing all fractions from the same flour had essentially the same diameter and spread rate as cookies made from the original unfractionated flour (*data not shown*).

Cookie doughs made with reconstituted soft-wheat flour (sample 1) had a larger diameter and faster spread rate than cookie doughs made with reconstituted hard-wheat flour (sample 5) (Table IV). Cookies made with reconstituted flour containing soft wheat gluten, soft wheat starch, and hard wheat WS (sample 4) had a significantly smaller diameter than cookies made with soft wheat reconstituted flour (sample 1) but were not different from cookies made with reconstituted flour containing hard wheat gluten, soft wheat starch, and soft wheat WS (sample 2) or with soft wheat gluten, hard wheat starch, and soft wheat WS (sample 3). Although the diameter of cookies made with reconstituted flour containing soft wheat gluten, soft wheat starch, and hard wheat WS (sample 4) was smaller than those made with soft wheat reconstituted flour (sample 1), these cookies were still significantly larger than those made with hard wheat reconstituted flour (sample 5). However, the spread rate of cookies made with reconstituted flour containing soft wheat gluten, soft wheat starch, and hard wheat WS (sample 4) was not different from those of cookies made with soft wheat reconstituted flour (sample 1). The spread rate of the reconstituted flour containing soft wheat gluten, soft wheat starch, and hard wheat WS (sample 4) was significantly lower than that of cookies made with reconstituted flour containing hard wheat gluten, soft wheat starch, and soft wheat WS (sample 2) or soft wheat gluten, hard wheat starch, and soft wheat WS (sample 3).

The diameter and spread rate of cookies baked from hard reconstituted flour (sample 5) and reconstituted flour containing soft wheat gluten, hard wheat starch, and hard wheat WS (sample 6) or

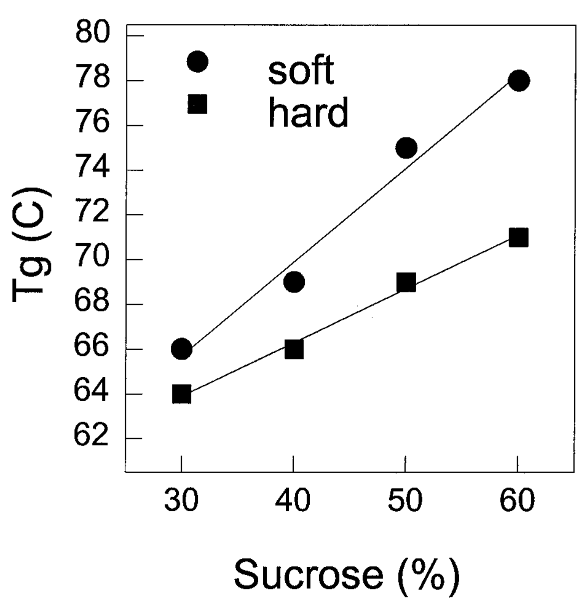

Fig. 2. Effect of sucrose level on the apparent glass transition temperature (T_g) of cookie doughs made with soft wheat (●) and hard wheat (■) flours.

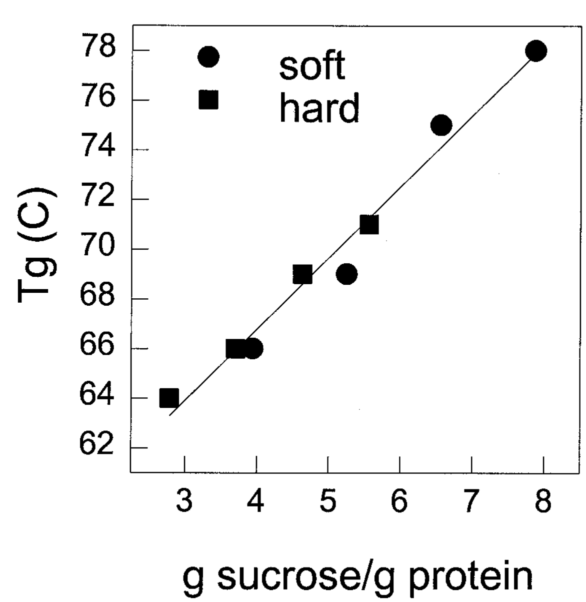

Fig. 3. Effect of sucrose level corrected for protein content on the apparent glass transition temperature (T_g) of cookie doughs made with soft wheat (●) and hard wheat (■) flours.

hard wheat gluten, hard wheat starch, and soft wheat WS (sample 8) were lower than those of cookies made with soft-wheat reconstituted flours (samples 1–4). However, the diameter and spread rate of cookies baked from reconstituted flour containing hard wheat gluten, soft wheat starch, and hard wheat WS (sample 7) were equivalent to those of cookies baked with soft-wheat reconstituted flour (sample 1).

Therefore, when the starch (prime and tailings) in hard wheat flour was replaced with starch (prime and tailings) from soft wheat flour (sample 7), the cookie diameter was equivalent to that of cookies baked with soft wheat flour (sample 1). Thus, hard wheat starch appears to be the fraction responsible for decreasing the diameter of cookies made with hard wheat flour. However, if hard wheat starch alone was the responsible fraction, then substituting hard wheat starch into soft wheat flour (sample 3) would decrease the diameter to that of cookies baked with hard wheat flour (sample 5). This was not the case; substituting hard wheat starch into soft wheat flour did not alter cookie diameter.

Closer investigation of the data revealed that reconstituted flours containing hard wheat starch in combination with either hard wheat gluten (sample 8) or hard wheat WS (sample 6) gave decreased cookie spread (Table IV). Hard wheat flour contains a relatively large quantity of damaged starch granules compared to soft wheat flour. Some of the starch molecules are fragmented when the granules are damaged, producing starch dextrins. Flour damaged starch content and soluble starch content were highly and significantly correlated ($r = 0.83$, $P < 0.01$). When flour is wetted, some of the starch dextrins are solubilized. Much of the soluble starch is found in the water soluble fraction during fractionation. The hard wheat flour contained significantly more soluble starch (0.354 ± 0.008%) than the soft wheat flour (0.152 ± 0.030%), which agrees with the findings of Simmonds et al (1973). Some of the soluble starch could also be trapped in or bound to the gluten during fractionation.

Both damaged and soluble starches affect dough viscosity. Damaged starch increases dough viscosity by absorbing relatively large quantities of water, whereas soluble starch increases the viscosity of the aqueous phase. The combination of these two factors may affect cookie spread. When the flour is fractionated, the damaged and soluble starches end up in different fractions. The damaged starch goes to the starch tailings fraction while the soluble starch goes to the WS fraction. Certain of the reconstituted flours contain both components but others do not. Therefore, the total level of damaged starch plus soluble starch may not be high enough in some of the reconstituted flours to significantly affect cookie spread. This may explain why reconstituted flours containing hard wheat starch plus hard wheat gluten (sample 8) or hard wheat WS (sample 6) produced small cookies, whereas reconstituted flours containing only one hard wheat fraction (samples 2–4) did not decrease cookie diameter.

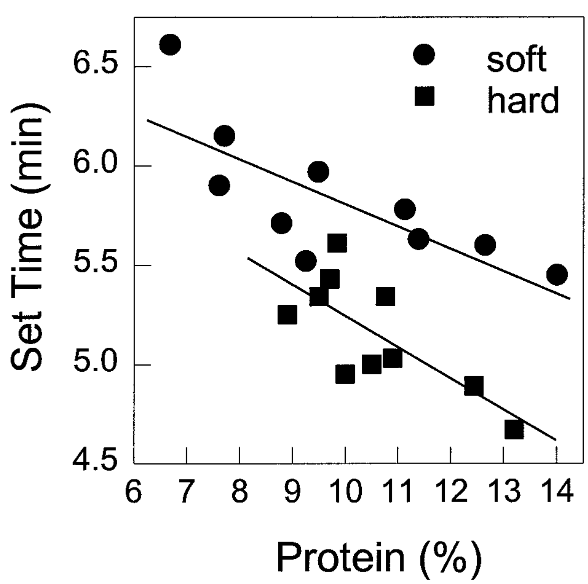

Fig. 4. Effect of flour protein content on the set time of cookie doughs made with soft wheat (●) and hard wheat (■) flours.

Soluble Starch Removal

Reconstituted flours were prepared with soft wheat gluten, hard wheat starch, and α-amylase-treated or untreated WS to determine the effect of removing soluble starch from the WS. Although the general trend is the same, the spread rate values presented in Table IV do not match those presented in Table V. This was most likely caused by aging of the flour between the two experiments. It is well documented that the baking properties of flour do change as the flour ages.

Reconstituted flours containing soft wheat gluten, hard wheat starch, and hard wheat WS (sample 10) produced cookies with a significantly lower spread rate than cookies made from reconstituted flour containing soft wheat gluten, hard wheat starch, and soft wheat WS (sample 9) (Table V). This was expected because damaged starch was present in the hard wheat starch and a high level of soluble starch was present in the hard wheat WS. Reconstituted flours containing soft wheat gluten, hard wheat starch, and hard wheat α-amylase-treated WS (sample 12) produced cookies with the same spread rate as cookies baked with reconstituted flour containing soft wheat gluten, hard wheat starch, and soft wheat WS (sample 9). Thus, removing the soluble starch from the hard wheat WS fraction increased spread rate (sample 12 vs. sample 10), indicating that high levels of soluble starch were detrimental to cookie spread. Removing soluble starch from the soft wheat WS fraction (reconstituted flours containing soft wheat gluten, hard wheat starch, and soft wheat α-amylase-treated WS [sample 13]) did not further increase cookie spread over that of

TABLE III
Effect of Sucrose Level on Spread Rate of Cookies Made with Soft Wheat and Hard Wheat Flours[a]

Flour Type	Sucrose (%)[b]	Spread Rate (mm/min)
Soft	60	7.8a
Soft	50	6.5b
Soft	40	5.7c
Soft	30	5.1d
Hard	60	4.6de
Hard	50	4.7de
Hard	40	4.5de
Hard	30	4.2e

[a] Means in a column followed by different letters are significantly different ($P < 0.05$).
[b] Flour weight basis.

TABLE IV
Effect of Switching Individual Flour Fractions on Diameter and Spread Rate of Cookies Made with Reconstituted Flours[a]

Sample	Flour Type			Diameter	Spread Rate
Number	Gluten	Starch	Solubles	(mm)	(mm/min)
1	Soft	Soft	Soft	185a	6.4ab
2	Hard	Soft	Soft	180ab	6.9a
3	Soft	Hard	Soft	181ab	7.0a
4	Soft	Soft	Hard	178b	6.0bc
5	Hard	Hard	Hard	162c	4.8d
6	Soft	Hard	Hard	165c	5.2cd
7	Hard	Soft	Hard	179ab	6.3ab
8	Hard	Hard	Soft	159c	5.0d

[a] Means in a column followed by different letters are significantly different ($P < 0.05$).

reconstituted flours containing soft wheat gluten, hard wheat starch, and untreated soft wheat WS (sample 9). Therefore, the level of soluble starch in the soft wheat WS was low and did not affect cookie spread.

Removal of soluble starch from soft wheat gluten (reconstituted flour containing soft wheat α-amylase-treated gluten, hard wheat starch, and soft wheat WS [sample 14]) did not improve cookie spread rate over that of reconstituted flours containing soft wheat gluten, hard wheat starch, and soft wheat WS (sample 9) (Table V). Cookies baked from reconstituted flours containing hard wheat α-amylase-treated gluten, hard wheat starch, and soft wheat WS (sample 15) had the same spread rate as cookies baked with hard wheat gluten, hard wheat starch, and soft wheat WS (sample 11). This indicates that either the soluble starch in the gluten was not important or was not removed during enzyme treatment. Therefore, no firm conclusions could be drawn regarding the effect of the soluble starch trapped in the gluten on cookie spread.

Effect of Soluble Starch on Cookie Spread Rate

Soluble starch content of the flour and cookie spread rate were highly and significantly correlated ($r = -0.84$, $P < 0.01$) (Fig. 5). However, the correlation was high because the hard wheat and soft wheat flours separated into two populations. Correlation was relatively poor within each population ($r = -0.426$ for soft wheat flour and $r = 0.115$ for hard wheat flour). Thus, soluble starch appears to be responsible for the difference in spread rate between cookies baked with soft wheat and hard wheat flours. However, soluble starch does not explain differences in spread rate within various soft wheat or hard wheat flours.

TABLE V
Effect of α-Amylase Treatment of Water Soluble and Gluten Fractions on the Spread Rate of Cookies Made with Reconstituted Flour[a]

Sample	Flour Type			Spread Rate
Number	Gluten	Starch	Solubles	(mm/min)
9	Soft	Hard	Soft	8.2a
10	Soft	Hard	Hard	7.5bc
11	Hard	Hard	Soft	7.1c
12	Soft	Hard	Hard*[b]	8.3a
13	Soft	Hard	Soft*	7.9ab
14	Soft*	Hard	Soft	7.5bc
15	Hard*	Hard	Soft	7.2c

[a] Means in a column followed by different letters are significantly different ($P < 0.05$).
[b] * = Treated with α-amylase.

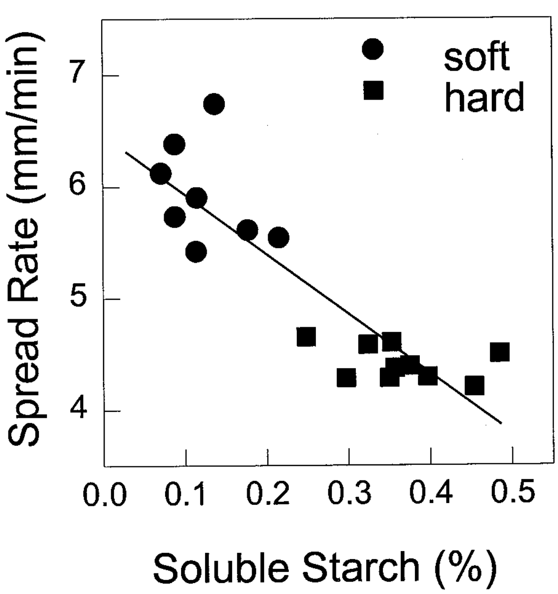

Fig. 5. Effect of soluble starch content of the flour on the spread rate of cookie doughs made with soft wheat (●) and hard wheat (■) flours.

CONCLUSIONS

Cookies made with soft wheat flour set (went through the apparent glass transition) later during baking than cookies made with hard wheat flour. Although sucrose affected both set time (apparent T_g) and a_w of the cookie dough, a_w did not explain the difference in set time between cookies made with hard wheat and soft wheat flours. Sucrose appeared to have its effect on cookie set time by acting as an antiplasticizer compared to the effect of water. The set time (apparent T_g) of cookie doughs made with soft wheat flour was increased more than that of cookie doughs made with hard wheat flour because the ratio of sucrose to protein was higher in the cookie doughs made with soft wheat flour. Flour protein content appeared to affect set time within various hard wheat flours and within various soft wheat flours. However, hard wheat and soft wheat flours fell into two separate populations. Thus, some other factor also affected the set time of cookies made with soft wheat and hard wheat flours.

Cookies made with soft wheat flour spread at a faster rate during baking than cookies made with hard wheat flour. Removal of the soluble starch from hard wheat flour decreased dough viscosity and increased cookie spread rate. Therefore, the high levels of soluble starch in addition to the high levels of insoluble damaged starch in hard wheat flour appeared to decrease cookie spread rate. However, soluble starch by itself did not explain the differences in spread rate within either type of flour.

ACKNOWLEDGMENT

We would like to thank Walter Bushuk of the University of Manitoba, Craig Morris and Doug Engle of the Western Wheat Quality Lab, Patrick Finney and Lonnie Andrews of the USDA Soft Wheat Lab, and Pat McClusky of the KSU Wheat Quality Lab for the flour and wheat cultivars; Ron Stevenson for milling; and Renu Mathew for running the TMA analysis.

LITERATURE CITED

Abboud, A. M., Rubenthaler, G. L., and Hoseney, R. C. 1985a. Effect of fat and sugar in sugar-snap cookies and evaluation of tests to measure cookie flour quality. Cereal Chem. 62:124-129.
Abboud, A. M., Hoseney, R. C., and Rubenthaler, G. L. 1985b. Factors affecting cookie flour quality. Cereal Chem. 62:130-133.
American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 10-52: approved September 1985, revised November 1988, November 1989, October 1991, and September 1992, reviewed October 1994. The Association: St. Paul, MN.
Cole, E. W., Mecham, D. K., and Pence, J. W. 1960. Effect of flour lipids and some derivatives on cookie-baking characteristics of lipid-free flours. Cereal Chem. 37:109-121.
Doescher, L. C., Hoseney, R. C., and Milliken, G. A. 1987a. A mechanism for cookie dough setting. Cereal Chem. 64:158-163.
Doescher, L .C., Hoseney, R. C., Milliken, G. A., and Rubenthaler, G. L. 1987b. Effect of sugars and flours on cookie spread evaluated by time-lapse photography. Cereal Chem. 64:163-167.
Donelson, J. R. 1988. The contribution of high-protein fractions from cake and cookie flours to baking performance. Cereal Chem. 65:389-391.
Eisenberg, A. 1984. The glass transition. Pages 55-95 in: Physical Properties of Polymers. J. E. Mark, A. Eisenberg, W. W. Groessely, L. Mandelkern, and J. L. Koening, eds. Am. Chem. Soc.: Washington, DC.
Finney, K. F., Yamazaki, W. T., and Morris, V. H. 1950. Effects of varying quantities of sugar, shortening, and ammonium bicarbonate on the spreading and top grain of sugar-snap cookies. Cereal Chem. 27:30-41.
Gaines, C. S. 1985. Associations among soft wheat flour particle size, protein content, chlorine response, kernel hardness, milling quality, white layer cake volume, and sugar-snap cookie spread. Cereal Chem. 62:290-292.

Hayashi, M., D'Appolonia, B. L., and Shuey, W. C. 1976. Baking studies on the pin-milled and air-classified flour from four hard red spring wheat varieties. Cereal Chem. 53:525-540.

Hoseney, R. C., Wade, P., and Finley, J. W. 1988. Soft wheat products. Pages 407-456 in: Wheat Chemistry and Technology, Vol. II. 3rd ed. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Hoseney, R. C., and Rogers, D. E. 1994. Mechanism of sugar functionality in cookies. Pages 203-226 in: The Science of Cookie and Cracker Production. H. Faridi, ed. Avi: New York.

Kaldy, M. S., Rubenthaler, G. L., Kereliuk, G. R., Berhow, M. A., and Vandercook, C. E. 1991. Relationships of selected flour constituents to baking quality in soft white wheat. Cereal Chem. 68:508-512.

Kalichevsky, M. T., Jaroszkiewicz, E. M., and Blanshard, J. M. V. 1992. Glass transition of gluten. 1: Gluten and gluten-sugar mixtures. Int. J. Biol. Macromol. 14:256-266.

Mathew, R., and Hoseney, R. C. 1994. Glass transition in cookie dough. (Abstr.) Cereal Foods World 39:638.

Miller, R. A., Mathew, R., and Hoseney, R. C. 1996. Use of a thermo mechanical analyzer to study an apparent glass transition in cookie dough. J. Thermal Anal. 47:1329-1338.

Nemeth, L. J., Williams, P. C., and Bushuk, W. 1994. A comparative study of the quality of soft wheats from Canada, Australia, and the United States. Cereal Foods World 39:691-700.

Rogers, D. E., Hoseney, R. C., Lookhart, G. L., Curran, S. P., Lin, W. D. A., and Sears, R. G. 1993. Milling and cookie baking quality of near-isogenic lines of wheat differing in kernel hardness. Cereal Chem. 70:183-187.

Roos, Y. H. 1987. Effect of moisture on the thermal behavior of strawberries using differential scanning calorimetry. J. Food Sci. 52:146-149.

SAS. 1990. Procedures Guide. Vers.6, 3rd ed. SAS Institute: Cary, NC.

Simmonds, D. H., Barlow, K. K., and Wrigley, C. W. 1973. The biochemical basis of grain hardness in wheat. Cereal Chem. 50:553-562.

Slade, L., and Levine, H. 1994. Glass transitions and water-food structure interactions. In: Advances in Food and Nutrition Research, Vol. 38. J. Kinsella, ed. Academic Press: San Diego, CA

Sollars, W. F. 1959. Effects of the water-soluble constituents of wheat flour on cookie diameter. Cereal Chem. 36:498-512.

Sollars, W. F., and Bowie, S. M. 1966. Effect of the subfractions of starch tailings on cookie diameter. Cereal Chem. 43:244-260.

Yamazaki, W. T. 1953. An alkaline water retention capacity test for the evaluation of cookie baking potentialities of soft winter wheat flours. Cereal Chem. 30:242-246.

Yamazaki, W. T. 1954. Interrelations among bread dough absorption, cookie diameter, protein content, and alkaline water retention capacity of soft winter wheat flour. Cereal Chem. 31:135-142.

Yamazaki, W. T. 1955. The concentration of a factor in soft wheat flours affecting cookie quality. Cereal Chem. 32:26-37.

Yamazaki, W. T. 1959a. Flour granularity and cookie quality. II. Effects of changes in granularity on cookie characteristics. Cereal Chem. 36:52-59.

Yamazaki, W. T. 1959b. The application of heat in the testing of flours for cookie quality. Cereal Chem. 36:59-69.

Yamazaki, W.T. 1962. Laboratory testing of flours and cookie quality research. Cereal Sci. Today 7:98-104, 125.

[Received September 26, 1996. Accepted February 23, 1997.]