

# A Mechanism for Cookie Dough Setting<sup>1</sup>

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## ABSTRACT

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Cookie doughs heated in an electrical resistance oven expanded at a specific temperature. The temperature at which rapid dough expansion began was strongly correlated to set time during baking. Scanning electron micrographs of cookie doughs and baked cookies showed that a change occurs during baking. Cookie doughs had a discontinuous structure, whereas baked cookies had a continuous structure. An apparent gluten glass transition was found in isolated gluten and in flour. The glass transition temperature ( $T_g$ ) of the hard wheat flour was significantly lower

than that of the soft wheat flour. The  $T_g$  of the flours approximated the temperature at which rapid dough expansion began in the resistance oven. We propose that when gluten undergoes a glass transition, it expands to form a continuous matrix, and viscosity increases, causing cookie doughs to stop spreading. The  $T_g$  was not the same for the hard and soft wheat flours, which accounts for at least part of the difference between these two flours.

Yamazaki (1955) developed a successful fractionation and reconstitution method for soft wheat flours. In fractionation studies conducted by several workers (Abboud et al 1985a; Sollars 1956, 1959; Sollars and Bowie 1966; Yamazaki 1955, Yamazaki and Donelson 1976, Yamazaki et al 1977) it was not clear which flour fraction, if any, controls cookie spread.

Bernardin and Kasarda (1973) showed that when flour particles are wetted, the protein hydrates and forms fibrils that have both adhesive and cohesive properties. Yamazaki and Donelson (1976) proposed that the same action may take place in some isolated gluten fractions in sugar solution. The gluten could form a network to provide cookie structure.

Recently, Hosenev et al (1986) showed that gluten undergoes a glass transition. The temperature of the transition is greatly affected by the moisture content of the sample. Glass transitions in polymers are characterized by a change in heat capacities (Richardson 1978).

Abboud et al (1985b) and Yamazaki (1959) proposed that the set-time of cookie doughs (the baking time at a specific temperature at which the cookie stopped spreading) was controlled by a temperature-mediated change in viscosity. Abboud et al (1985b) believed that a lower temperature change in viscosity was the factor that makes hard wheat flour cookies set at a lower temperature than those made from soft wheat flour.

The objectives of this study were to determine the mechanism by which cookie doughs stop spreading and to identify which flour fraction is responsible for differences in soft wheat flour quality.

## 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. A hard wheat flour from Ross Mills, Wichita, KS, containing 11.8% protein, 13.5% moisture, and 0.46% ash was used in differential scanning calorimetry (DSC) studies. Hard wheat gluten (76.0% protein, 7.39% moisture) was from Midwest Grain Products, Atchison, KS. 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 1 sodium bicarbonate (Arm and Hammer), from Church and Dwight Co., Princeton, NJ, and a commercial hydrogenated all-vegetable shortening, Crisco, from Procter & Gamble were used.

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### Cookie Baking.

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

### Steaming of Cookie Doughs

Cookie doughs prepared with granular sucrose, sucrose syrup, fructose syrup, and glucose syrup were steamed instead of baked. Each cookie was mixed, then rolled and cut on the regular baking sheet. A turkey roaster was placed on two hot plates, water was added and heated to boiling. The cookie sheet was then balanced on the metal support rack of the roaster. The roaster lid was placed over the sheet, and cookies were steamed for 10 min.

### Resistance Oven Baking

Cookie doughs were heated in an electrical resistance oven as described by Abboud et al (1985b). After heating, force to compress the sample was measured using an Instron universal testing machine (Abboud et al 1985b). Cookie doughs heated to 30, 35, 40, 45, and 50°C were cooled to 27°C before testing. In addition, cookie doughs were heated to 30, 50, 70, and 90°C, and compression tests were run immediately upon reaching the desired temperature.

The electrical resistance oven was equipped with centimeter rulers on each end, between the cookie plates. The cookie doughs were placed in the oven and were leveled off at approximately the 3.5-cm mark. Cookie doughs were prepared by the method of Finney et al (1950), but the  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{NaCl}$  were removed. In their place 0.75%  $\text{NaCl}$  was added. Syrups (sucrose, glucose, and fructose) were used instead of crystalline sugar in some experiments. In another experiment, sucrose concentration was varied (0, 15, 30, 45, and 60%, based on flour weight). A constant volume of solution (water plus dissolved sugar) was maintained. The volume displacement for sugars was obtained from West and Astle (1982).

In one experiment, cookie doughs were prepared with the sodium bicarbonate in the cream removed. In a related experiment, the bicarbonate was omitted and sufficient 0.09N  $\text{NaOH}$  was added to adjust the dough pH to that of the control (pH 7.58).

A variable transformer was used to control the voltage so that the doughs heated at a constant rate. Height (cm) and temperature readings (°C from thermocouple) were taken at 30-sec intervals until the dough had expanded to the top of the oven. Each experiment was replicated four times. The temperature at which rapid dough expansion began was determined using regression analysis. One segmented line along with one quadratic function

were fit to the data. The temperature at which rapid dough expansion began was taken as the intersection point of these two functions (Fig. 1). Means were compared by the least significant difference method.

#### Instron Measurements.

Cookie doughs were prepared according to micro method III (Finney et al 1950). The doughs were first placed on baking sheets and rolled as usual but then were placed in petri dishes and immersed in acetone for two days. The samples were removed from the petri dishes, and the residual acetone was removed by blowing air over the samples with a fan. The dried samples were cut into 1-cm<sup>2</sup> squares with a razor blade. Sample height was 0.8 cm. Baked cookies were cut into 1-cm<sup>2</sup> squares without drying in acetone.

The cookie and dried dough samples were tested on the Instron using the 50-kg compression load cell. The crosshead was equipped with a flat-ended plunger having a diameter of 3.6 cm. Samples were placed on a flat plate centered under the plunger. Force to compress the sample to 3 mm was recorded. Crosshead speed was set at 10 mm/min and chart speed was 25 mm/min. Ten samples were tested for each variable.

#### Scanning Electron Microscopy

Cookie doughs were prepared by micro method III (Finney et al 1950) but the NaHCO<sub>3</sub>, NH<sub>4</sub>Cl, and NaCl in the aqueous solution were removed. After mixing, several 1-cm<sup>3</sup> pieces of dough were placed in a sample jar. Baked cookies were broken into pieces of similar size (approximately 1-cm<sup>3</sup>) and were placed in separate sample jars. All samples were immersed in hexane, and the jars were capped. After six days, hexane was decanted and the samples were immersed in acetone. After two days, the acetone was decanted, and the samples were air-dried overnight. The samples were then mounted on stubs for examination with scanning electron microscopy.

#### Determination of Glass Transition Temperature

A hard and a soft wheat flour were fractionated using the procedure of Rogers and Hoseney (1985). Only the gluten fraction was retained. The gluten was frozen, lyophilized, and then ground using an Oster blender. A Perkin-Elmer DSC II equipped with intercooler was used to determine the temperature of the glass transition of the gluten. Both the hard wheat gluten (91.8% protein, 0.97% moisture) and the soft wheat gluten (83.4% protein, 0.87% moisture) were scaled into aluminum sample pans. A sample size of 4.5 mg was used. The glutes were tempered by placing the scaled gluten and sample pan into a desiccator over water at room temperature. Periodically the pan plus sample was removed from the desiccator and weighed. This was repeated until the desired moisture content was obtained. The sample moisture was taken as:

$$\frac{\text{Final weight} - \text{Dry gluten weight}}{\text{Final weight}} \times 100\%$$

The pans were sealed, and samples were scanned at a sensitivity of 0.5 mcal/sec, heated at 10°C/min, and cooled at 20°C/min. Following the cooling, samples were rescanned. Samples were scanned from a minimum of 2°C up to a maximum of 157°C. The temperature of the glass transition was taken from the second scan; it was the midpoint of the shift in the heat capacity of the sample.

Flours were dried and tempered to give samples with different moisture contents. The flour was dried by spreading it thinly on trays and passing air over the surface. The flour was tempered by spreading it thinly on trays and placing them in a humidified chamber. Moistures of the flours were determined by AACC method 44-15A (AACC 1976).

Flour samples of 22.1 to 22.9 mg were scaled into stainless steel sample pans. All samples were scanned in the calorimeter at a sensitivity of 0.5 mcal/sec, heated at 10°C/min, and cooled at 20°C/min. All samples were scanned from a minimum of 2°C up to a maximum of 127°C. Immediately after cooling, samples were rescanned. Temperature of the glass transition was taken as the

midpoint of the shift in heat capacity from the second scan. Results were analyzed using regression analysis. Slopes of the two lines were compared by computing a *t* statistic.

#### Effect of Cookie Ingredients on Gluten T<sub>g</sub>

The micro method III cookie formula of Finney et al (1950) was used, replacing flour with commercially obtained hard wheat gluten. Cookie formula ingredients were sequentially added to gluten, always maintaining the proper ratio of ingredients to gluten (based upon gluten = flour). Optimum water content was chosen as 20% of the gluten weight (14% moisture basis). Glucose (dissolved in water) was used instead of sucrose in these trials. All dry ingredients were blended with the gluten before scaling in the calorimeter pans. When fat was used, it was also blended with the gluten. The samples were not mixed into a dough, but instead, water or glucose syrup was first scaled into the aluminum sample pan; then, the dry gluten or blended ingredients were added. The pans were sealed and scanned at 0.5 mcal/sec, 10°C/min, from 7 to 127°C. Ammonium bicarbonate was omitted from the formula so that the hermetic seal of the pan would not be disrupted.

## RESULTS AND DISCUSSION

#### Effect of Humidity on Cookie Setting

When sugar-snap cookies are baked, the surface becomes dry and cracks as the cookie spreads. Previous studies on surface cracking showed that cookies prepared with glucose and fructose syrups spread less than those prepared with sucrose (Doescher and Hoseney 1985). If surface drying controls the setting of cookies, then no differences should exist when the cookies are baked in a 100% relative humidity environment (steamed) where the surface cannot dry. Cookie diameter varied with the sugars used independently of whether the cookies were baked or steamed (Table I). Clearly, the cookies were not larger as a result of steaming. Hence, surface drying does not control cookie setting.

#### Compression Testing of Cookie Doughs

Yamazaki (1959) and Abboud et al (1985b) proposed that the set time (baking time at which the cookie dough stops spreading) of a

TABLE I  
Effect of Type of Sugar and Heat on Cookie Diameter<sup>a</sup>

Sugar	Baked (cm)	Steamed (cm)
Granular sucrose	8.97	8.59
Sucrose syrup	8.80	8.20
Glucose syrup	7.95	7.41
Fructose syrup	7.21	7.10

<sup>a</sup> Mean of two trials with soft flour.

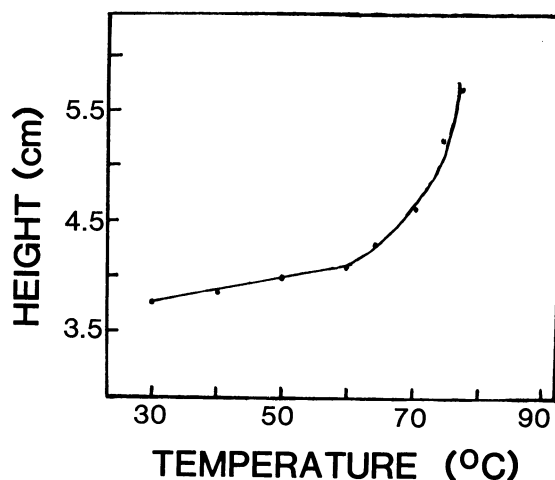


Fig. 1. Change in dough height as a function of temperature, measured in an electrical resistance oven.

cookie dough is controlled by a temperature-mediated change in viscosity. The force to compress cookie dough with the Instron was used to test this assumption. The force required increased as dough temperature was increased between 30 and 50°C (Fig. 2). The force required to compress the doughs was higher for the control (sucrose-containing) dough than for the dough containing glucose or fructose, particularly at higher temperatures (40–50°C). This did not agree with baking data for cookies produced with the same flours (Doescher et al 1986). The sucrose-containing cookie dough gave a much larger spread than either the glucose- or fructose-containing cookie dough did. We had hypothesized that the increase in force would be rapid and occur at a low temperature for cookie dough made with glucose or fructose. This would have explained their smaller diameter, but clearly this was not the case.

The doughs heated in the resistance oven contained no leavening; however, they expanded suddenly and rapidly at moderate temperatures (70°C). Because this temperature is not high enough for water to be converted to steam, the driving force for expansion was not clear. Although the vapor pressure of water increases progressively with temperature, the cookie dough expansion started suddenly at a specific temperature and then increased rapidly and progressively with temperature (Fig. 1). The cause for this sudden expansion is not clear. If it resulted from flour particle hydration, an exotherm would be found during DSC scans of cookie dough; however, no such exotherm occurred. The cause for a sudden start of dough expansion was still not clear.

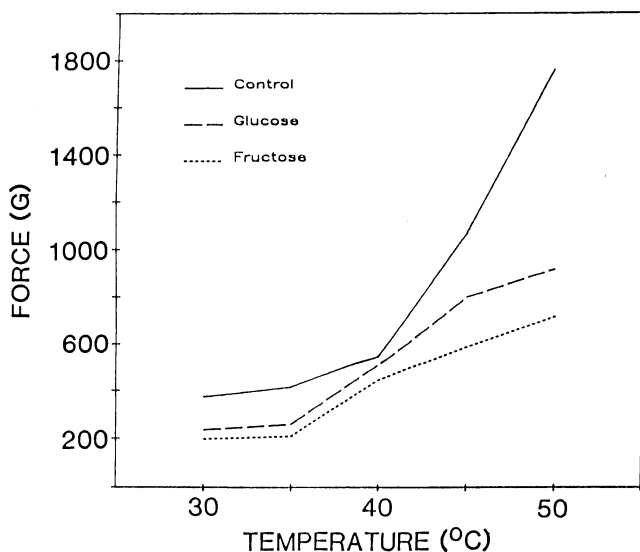


Fig. 2. Force required to compress cookie doughs from different sweeteners. All doughs were cooled to 27°C before testing.

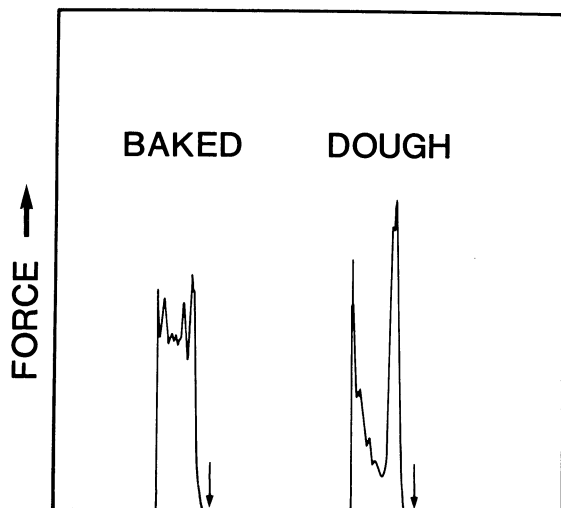


Fig. 3. Breaking strength of cookie doughs and baked cookies measured on the Instron universal testing machine.

### Breaking Strength

If, as suggested by Flint and co-workers (1970), the difference between baked cookies and cookie dough is the formation of a continuous protein matrix, the manner in which they break under force should differ. The breaking strength of dried cookie doughs and baked cookies was compared using the Instron. Although more force was required to break cookie doughs, once the dough failed, no more force was necessary to move through the sample (Fig. 3). Less force was required to break baked cookies, but the amount of force to continue moving through the sample was constant.

### Scanning Electron Microscopy

Scanning electron micrographs were taken of sections of unheated but dried cookie dough and baked cookies. At low magnification, the baked cookie crumb seemed to be a more continuous system than the cookie dough. The baked cookie appeared to have a well-developed matrix (Fig. 4). The findings of the last two sections confirm the results of Flint et al (1970). This suggests that a baked cookie has a continuous matrix, but a cookie dough does not.

### Determination of the Start of Rapid Dough Expansion

Cookie doughs prepared with hard wheat flour, sucrose syrup, glucose syrup, or fructose syrup but no leavening all expanded at lower temperatures than doughs prepared with granular sucrose (Table II). Doughs prepared without sodium bicarbonate in the cream (pH 6.55) did not expand until high temperature (91°C). Expansion at this temperature may be caused by water vaporization. Doughs prepared without sodium bicarbonate but adjusted to similar pH (7.59) with NaOH expanded at low temperature (49°C). The large change in the temperature of the start of rapid dough expansion as a function of pH clearly is not an effect of water vaporization. Because no leavening was present in this dough, the expansion could not result from the formation of leavening gases; hence, the expansion phenomenon was a property of the flour.

To determine whether the temperature at the start of rapid dough expansion in the resistance oven was related to the set time during baking, doughs were prepared with hard wheat flour, granular sucrose, sucrose syrup, fructose syrup, or glucose syrup. The correlation coefficient between the temperature at the start of rapid dough expansion and set time was 0.91 (Table II). This indicated that the temperature at the start of rapid dough expansion in the resistance oven was closely related to the set time during baking (Fig. 5).

### Determination of Glass Transition Temperature ( $T_g$ )

The hard and soft wheat flours used in baking trials were fractionated, and the resulting glutes were compared by DSC. The temperature of the glass transition was sensitive to moisture content (Fig. 6) as reported by Hosney and co-workers (1986). However, the glass transition temperatures for the two glutes were not significantly different. However, there could be an interaction between flour components that shifts the glass transition temperature. Fractionating the flour may destroy that interaction.

When samples of the hard and soft wheat flours were tested over a range of moisture contents, the glass transition temperatures of the two flours fell on separate curves (Fig. 7). At equal moisture contents, the apparent  $T_g$  of hard wheat flour was at significantly lower temperatures than the apparent  $T_g$  of the soft wheat flour. When regression lines were constructed through the data points, the difference in their slope was significant at the  $P = 0.025$  level. For the moisture content range typically used in baking, the temperature of the glass transition (79°C) closely approximated the temperature of the start of rapid dough expansion in the resistance oven (74°C).

At comparable moisture levels, the glass transition temperature of gluten in flour was approximately 30°C higher than for the isolated gluten (Figs. 6 and 7). An interaction between flour components may account for this difference. The interaction

between gluten and flour components may account for some of the difference between hard and soft wheat flours.

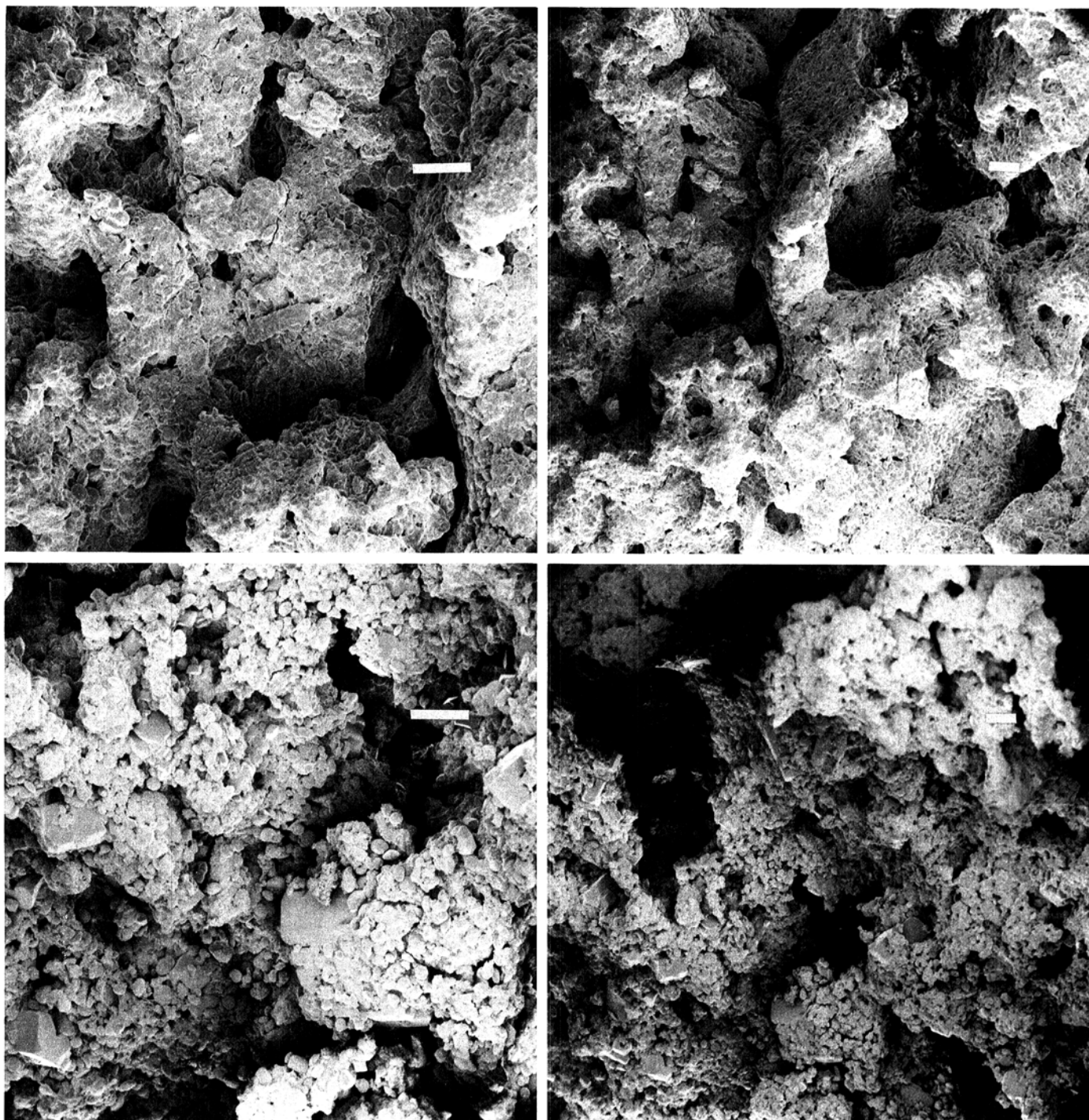
#### Effect of Cookie Ingredients on the $T_g$

It was only with large samples or at a high sensitivity that the glass transition of gluten in flour could be detected with the DSC. Flour contains about 10% or less gluten. The gluten in flour is probably diluted so greatly that it is difficult to detect a glass transition at lower sensitivity. When flour is blended with other ingredients, the gluten becomes an even smaller percentage of the total sample. This explains why the glass transition of gluten has not been detected in complex dough systems. To determine the effect of various cookie ingredients on the glass transition of

**TABLE II**  
Temperature of Rapid Dough Expansion and Set Time During Baking for Cookie Doughs Made with Different Flours and Sugars

Sugar	Flour	Dough Expansion Temperature <sup>a</sup> (°C)	Setting Time (min)
Granular sucrose	Soft	74 a	7.65
Sucrose syrup	Soft	56 b	6.85
Glucose syrup	Soft	53 bc	5.59
Fructose syrup	Soft	44 c	5.16
Granular sucrose	Hard	55 b	5.66

<sup>a</sup> Means with different letters denote statistically significant differences at the 0.05 level of probability.



**Fig. 4.** Scanning electron micrographs of cookie doughs and baked cookies. Top, cookie dough 50× left, 100× right; bottom: baked cookie 50× left, 100× right.

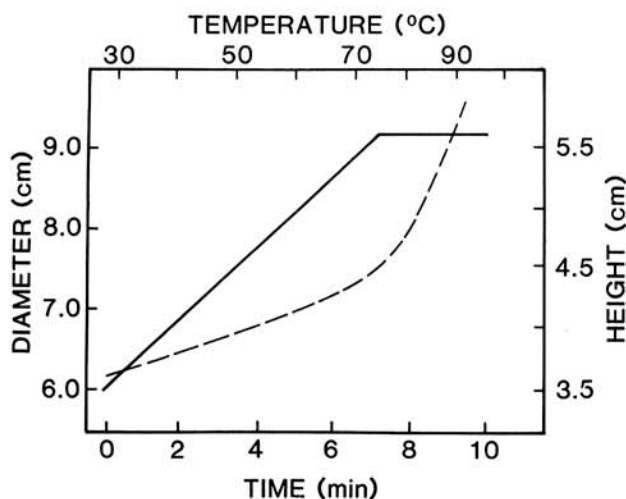


Fig. 5. Relationship between expansion temperature in the resistance oven and set time during baking: cookie diameter vs. baking time (solid line), dough height vs. temperature (dashed line).

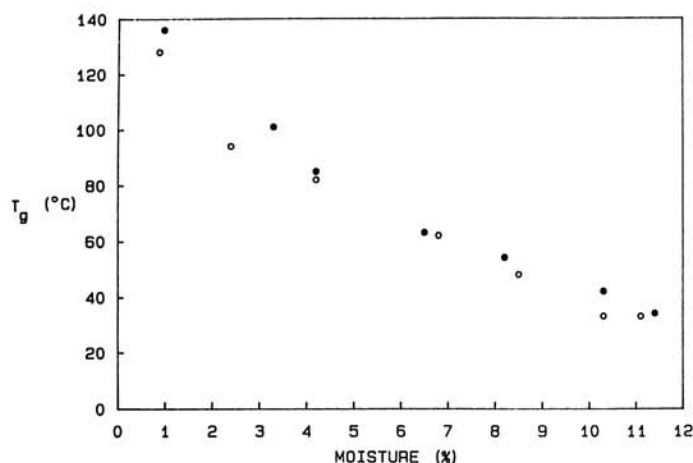


Fig. 6. Glass transition temperature of gluten vs. moisture content: (●) hard wheat, (○) soft wheat.

gluten, the problem of gluten dilution was avoided by replacing all of the flour in the cookie formula with gluten.

As no apparent difference was observed between the glass transition temperatures of the soft and hard wheat glutes studied, commercially obtained hard wheat gluten was used. Cookie dough ingredients were added one at a time to study their effect on the glass transition temperature of gluten. Glucose was dissolved in the formula water to avoid the sugar-dissolving peak (Abboud and Hosney 1984), which would mask the glass transition. Sucrose could not be used for this study because it crystallized readily in the presence of gluten, resulting in a very large sucrose dissolution peak.

Gluten at 7.39% moisture had a glass transition at approximately 82°C. Addition of formula water (20% of gluten weight) depressed that transition to 33°C (Table III). The addition of 1% sodium bicarbonate (based on gluten) shifted the glass transition back up to high temperature (81°C). Glucose (60% based on the gluten) also shifted the glass transition but not as much as the bicarbonate. A combination of glucose (60%) and bicarbonate (1%) had approximately the same effect as glucose alone. The addition of salt, nonfat milk solids, and fat (at their formula levels) to the gluten-glucose-bicarbonate mixture had no significant effect on the glass transition temperature. From these studies, it appears that both glucose and bicarbonate move the glass transition of gluten to a higher temperature.

Several levels of bicarbonate were added to gluten to determine if the shift in glass transition temperature was concentration-dependent. The glass transition remained at essentially the same

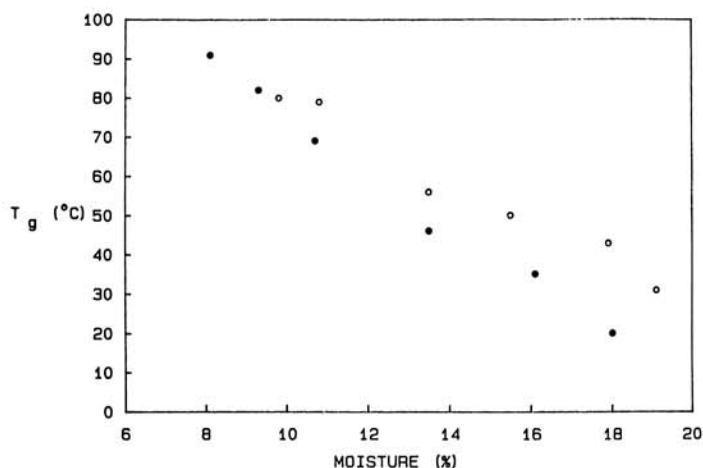


Fig. 7. Glass transition temperature of gluten in flour vs. moisture content: (●) hard wheat flour, (○) soft wheat flour.

TABLE III  
Effect of Cookie Ingredients  
on the Glass Transition Temperature ( $T_g$ ) of Gluten

Sample <sup>a</sup>	$T_g^b$ (°C)
Gluten	85
Gluten + H <sub>2</sub> O	34
Gluten + 1% NaHCO <sub>3</sub>	88
Gluten + 0.50% NaHCO <sub>3</sub>	75
Gluten + 0.25% NaHCO <sub>3</sub>	78
Gluten + glucose syrup	75
Gluten, glucose, 1% NaHCO <sub>3</sub>	80
Gluten, glucose, 1% NaHCO <sub>3</sub> , 1% NaCl	79
Gluten, glucose, 1% NaHCO <sub>3</sub> , 1% NaCl, 3% NFDM <sup>c</sup>	70
Gluten, glucose, 1% NaHCO <sub>3</sub> , 1% NaCl, 3% NFDM, 30% fat	66
	61
	68
	66
	64
	68

<sup>a</sup>All samples except gluten alone contain 20% water.

<sup>b</sup>Replicate data given.

<sup>c</sup>NFDM = Nonfat dry milk.

temperature when 0.25, 0.50, and 1.0% sodium bicarbonate were used (Table III). A small amount of bicarbonate may have shifted the pH of the sample so that the transition always occurred in the same temperature range. It was not clear whether the  $T_g$  was pH dependent.

## CONCLUSION

When cookie dough is mixed, flour protein becomes hydrated but does not expand because it is below the glass transition temperature. During heating the dough flows until the flour undergoes an apparent glass transition that allows it to expand and form a continuous matrix. As a result, the viscosity increases, causing the cookie dough to stop spreading. Certain cookie ingredients affect the temperature of the glass transition. The temperature of the glass transition was not the same for the hard and soft wheat flours studied, which accounts for some of the differences between these flours.

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