Influence of Chemical and Physical Modification of Soft Wheat Protein on Sugar-Snap Cookie Dough Consistency, Cookie Size, and Hardness

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ABSTRACT

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Across-cultivar mixograph patterns of 64 flours were evaluated together with protein content. They were found to predict sugar-snap cookie diameter less well than a combination of break flour yield, alkaline water retention capacity, and protein content. Soft wheat proteins within five cultivars were modified with potassium iodate, L-cysteine, *N*-ethylmaleimide, and dithioerythritol. The protein-modifying agents significantly affected cookie spread and weight, although they had relatively little effect on dough consistency as measured by the Instron universal testing machine. Proteins within cultivars were also modified by mixing (at two levels of dough water addition) sugar-snap cookie doughs at four mixing times. Dough liquid level affected cookie spread and top grain and universal testing machine consistency. Longer mixing time increased sensory ranking of cookie hardness, although hardness increased without a significant change in dough consistency. Any gluten developed during mixing was relatively small compared with the increase observed in cookie hardness. Soft wheat proteins functioned by affecting sugar-snap cookie size, weight, and texture without forming an extensive gluten network.

Essential for the baking quality of most products traditionally made from hard wheat flours, a developed gluten network is variously desired in products produced from soft wheat flours. Yeast and chemically leavened crackers, pretzels, and American biscuits require some (usually minimized) developed gluten for structure (Hoseney et al 1986). Flint et al (1970) studied three types of English biscuit doughs and observed that short sweet biscuit doughs showed no microscopic evidence of a continuous gluten network. Semisweet biscuit and cream cracker doughs (which receive sheeting) showed definite gluten development.

A sufficient amount of water to hydrate wheat flour proteins and addition of various forms of mechanical energy will develop gliadin and glutenin proteins, lipids, and pentosans into the useful entity, gluten. At the appropriate ratio of flour and water, gluten (along with the other flour components) forms a viscoelastic dough. If there is too little water, or interfering substances such as the fat and sugar in a cookie dough are added, proteins will not be properly hydrated. That would produce a less than optimally rheologically active dough (for breadmaking). Too much water, as in a cake, waffle, or wafer batter, interferes with the necessary agglomeration of the proteins to form an extensive viscoelastic network during mixing.

Finney et al (1950) cautioned that sugar-snap cookie doughs should receive minimum mixing action during test baking. Though not as rheologically sensitive as doughs containing developed gluten, subsequent handling (rolling) of cookie doughs has been shown to reduce cookie spread (Gaines et al 1988). That suggests the protein precursors to gluten have a propensity in sugar-snap cookie doughs to associate, though they may only form relatively few functional intra- and intermolecular bonds. If that affects

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cookie size, it may also affect aspects of cookie texture.

Sugar-snap cookie doughs have a relatively high concentration of sugar and fat (shortening) and a low amount of water. Those ingredients make a dough with a sufficiently viscous and cohesive nature. The plastic nature of the shortening and probably some hydrogen bonding give the sugar-snap cookie dough the desired consistency of handling, without an extensive gluten network (Hoseney 1986).

It is likely a mistake to view the proteins of soft wheat flour (the major portion of which are the gluten precursors, gliadin and glutenin) as functionally inert in cookie doughs (especially during baking). Good soft wheat rheological properties should not necessarily be considered to be opposite (weaker) than those of a hard wheat (Hoseney et al 1988). Tsen and Anderson (1963) found the disulfide content of 10 soft wheats to be greater, on a protein basis, than that of 10 hard wheats. There were no differences in sulfhydryl content between the two classes.

As a cookie bakes, the plastic shortening quickly melts, the leavening produces gas, cookie viscosity decreases, the dough expands in all directions, and the proteins become more hydrated. There are at least two theories concerning the mechanism by which cookie doughs stop expanding (spreading) during baking. Both involve and emphasize the critical function of soft wheat flour proteins. Doescher et al (1987) suggest that flour proteins swell when their glass transition temperature is reached. A continuous phase or network is formed that decreases water mobility and increases dough viscosity, stopping the spreading of the dough. Presumably, cultivar cookie flour quality is partially determined by variation in glass transition temperature. In contrast, Slade et al (1989) suggest that proteins in good quality flours exhibit viscous expansion and creep followed by structural collapse. Poor quality flours exhibit elastic expansion followed by elastic shrinkage. Presumably, soft wheat cultivars differ in those rheological properties.

Those differences may not necessarily result in differences in gluten mixing strength. However, a recent publication (Bettge et al 1989) observed a 0.797 correlation between cookie diameter and an algorithm of the alveograph *P* values and flour protein content. An analogous situation may exist between cookie diameter and another method for evaluating (developed) protein quality such as the mixograph and including protein content in an algorithm.

There have been numerous studies and reviews of the effects of oxidizing, reducing, and blocking agents on the sulfhydryl and disulfide groups of hard wheat gluten (Tsen and Anderson 1963, Mauritzen 1967, McDermott et al 1969, Tsen 1969, Murthy and Dahle 1969, Ponte 1971, Tsen 1973, etc.). They focused almost exclusively on practical interactions involved in developed gluten. When mixed in air, hydrated sulfhydryl groups begin to disappear. However, Kaufman et al (1986) state that the thiol-disulfide interchange between large molecular weight gluten molecules "in their native state" has not been clearly demonstrated.

Bloksma and Bushuk (1988) reviewed the effects of the following agents on the rheology of developed gluten in hard wheat doughs. Potassium iodate is a fast-acting sulfhydryl oxidizing agent that increases gluten elasticity. L-Cysteine cleaves disulfide bonds, decreasing gluten elasticity. *N*-ethylmaleimide (NEMI) is a sulfhydryl blocking agent that reduces thiol-disulfide interchange. It initially increases dough elasticity but makes doughs susceptible to prolonged mixing. Dithioerythritol cleaves disulfide bonds and interacts with the resulting thiol groups, removing them from reactivity and decreasing gluten elasticity.

Those four agents have been used to alter the rheological properties of developed hard wheat glutens. They should also be useful in studying functionality (as theorized above) of soft wheat proteins during the test baking of sugar-snap cookies. Presumably, in most soft wheat product doughs and batters, gliadin and glutenin exist as relatively unassociated molecules, with their reactive sites (thiol included) eminently available for intra- and inter-molecular associations, given sufficient hydration and energy input.

Objectives were to study the influence of soft wheat flour protein on sugar-snap cookie quality both across and within cultivars. A study was designed to determine the relative importance across soft wheat cultivars of flour protein quantity alone and combined with mixograph quality to the results of the sugar-snap cookie test baking method. Another study altered proteins within cultivars by adding oxidation, cleaving, and blocking agents and observing those effects on sugar-snap cookie dough consistency and cookie spread. A final study altered proteins within cultivars by varying dough mixing and dough liquid level to determine the effects of those treatments on dough consistency, cookie diameter, cookie top grain, and cookie hardness.

MATERIALS AND METHODS

Flours and Milling

Sixty-four flours from 58 soft wheat cultivars were milled into straight-grade flour on an Allis-Chalmers mill and break flour yield calculated (Yamazaki and Andrews 1982). They were used in the across-cultivar mixograph-protein content portion of the study. Five other soft red winter cultivars (Adder, Auburn, Becker, Cardinal, and Severn) were freshly milled and stored under nitrogen. They were used in the chemical agent portion of the study. Becker and the soft red winter cultivar, Caldwell, were evaluated in the mixing time and cookie hardness ranking study.

Baking and Analyses

Mixograph mixing time and peak height were determined (AACC 1983) for the 64 flours. α-Amylase content, alkaline water retention capacity (AWRC), and protein content were determined on the first five cultivars using AACC methods (AACC 1983). All flours were baked into sugar-snap cookies (AACC 1983).

Dough Measurements

Dough consistency was determined with an Instron universal testing machine (UTM; model 1000). The instrument was equipped with a 50-kg transducer and 3.6-cm diameter plunger. The crossbar was operated at 5 cm/min over a range of 0–20 kg. Doughs were held at room temperature in sealed plastic bags for 30 min. They were then divided and rolled in the normal manner, except a sheet of aluminum foil was placed on the baking sheet. The rolled dough was removed from the foil and placed on the UTM platen for measurement. Doughs were compressed from their 6-mm height (as rolled on the cookie sheet) to 3 mm. Dough consistency was the resistance offered to that 50% compression.

Chemical Treatments

Standard solutions of 0.12*M* of potassium iodate, L-cysteine, NEMI, and dithioerythritol were prepared for the baking studies. Using 0.5 ml of the 0.12*M* solutions to replace 0.5 ml of cookie dough liquid added 1.5 millequivalents of each chemical to 1 g of flour. Tsen and Anderson (1963) analyzed 15 flours and reported a maximum of 1.5 millequivalents of sulfhydryl groups per gram of flour.

Hardness Ranking

Four tasters ranked the hardness of cookies produced from four dough mixing times (15, 30, 60, and 90 sec), each from two dough liquid levels (6.5 and 7.5 ml).

Replication and Analyses

All doughs, bakes, analyses, and hardness rankings were replicated, and data were analyzed by analysis of variance. All replication effects on treatments were nonsignificant at the $P = 0.05$ level of probability. Least significance difference (LSD) values were calculated from pooled replication mean squares and used to compare treatment and cultivar means.

RESULTS AND DISCUSSION

Correlation of Mixing Strength and Cookie Spread

Sugar-snap cookie diameters of 64 soft wheat flours were correlated by mixograph peak height and peak time, AWRC,

TABLE I
Correlation Coefficients[a] Among Cookie Diameter, AWRC,[b] Break Flour Yield, and Mixograph Peak Height and Time for 64 Soft Wheat Flours

Source	Cookie Diameter	AWRC[b]	Flour Yield	Flour Protein	Mixograph Height	Mixograph Time
Cookie diameter	...					
AWRC	−0.47	...				
Break flour yield	0.33	−0.05	...			
Flour protein	−0.27	0.20	0.04	...		
Mixograph peak height	−0.29	0.20	−0.21	0.71	...	
Mixograph peak time	0.06	0.15	0.44	−0.04	−0.22	...

[a] Correlation coefficients greater than 0.25 are significant at the $P = 0.05$ level of probability.
[b] Alkaline water retention capacity.

TABLE II
Student's *t* Values and Their Levels of Probability for Independent Variables in a Multiple Linear Regression Prediction of Sugar-Snap Cookie Diameter for 64 Wheats

Independent Variable	Student's *t*	Level of Probability
Flour protein	−1.4	0.18
Break flour yield	2.4	0.02
AWRC[a]	−3.6	0.00
Mixograph peak height	−0.4	0.70
Mixograph peak time	−0.5	0.62

[a] Alkaline water retention capacity.

TABLE III
Flour Protein Content, AWRC,[a] Break Flour Yield, and α-Amylase Content for Five Soft Wheat Cultivars

Cultivar	Flour Protein (%)	AWRC (%)	Flour Yield (%)	α-Amylase (abs)
Adder	10.4	50.1	30.0	0.042
Auburn	10.5	50.8	28.1	0.037
Becker	7.8	52.7	35.7	0.054
Cardinal	8.6	51.0	31.8	0.045
Severn	8.1	49.9	33.0	0.037

[a] Alkaline water retention capacity.

and kernel softness (break flour yield) (Table I). Cookie diameter was correlated, in decreasing order of association, with AWRC, break flour yield, flour protein content, mixogram peak height, and mixogram peak time. Mixograph height was highly influenced by protein content. Mixing time usually has large variations across cultivars at any given level of protein. However, mixing time tended to be somewhat longer in cultivars having softer kernel texture.

AWRC was relatively independent of protein quantity and mixing quality (mixograph peak time and height). Protein content is weakly negatively correlated with the cookie diameter of soft wheats (Yamazaki 1954, Yamazaki and Lamb 1962, Kissell and Yamazaki 1975, Abboud et al 1985, Gaines 1985, and Bettge et al 1989). The correlation of cookie diameter and mixograph strength was no greater than that between cookie diameter and protein content. In general, larger sugar-snap cookies were made from softer textured wheats that produced lower protein flours, with lower AWRC values, and lower mixograph peak heights (perhaps only an indication of lower protein levels).

Using those parameters, a best-fit multiple regression equation was developed to predict cookie diameter. The following equation explained 59% ($r = 0.77$) of the variation in cookie diameter, with a standard error of estimate of 0.27 cm:

$$\mathrm{CD} = 21.42 - 0.067(\mathrm{P}) + 0.023(\mathrm{BFY}) - 0.074(\mathrm{AWRC})$$

where CD = cookie diameter, P = flour protein content, BFY = break flour yield, and AWRC = alkaline water retention capacity ($n = 64$). Table II shows the relative importance of the Student's *t* values (and levels of probability) for independent variables in a regression equation. Higher absolute Student's *t* values contribute more to the prediction. The best-fit equation did not contain either mixograph peak height or mixograph time, alone or with protein content, a relationship previously shown between alveograph *P* and protein content (Bettge et al 1989).

Effects of Sulfhydryl/Disulfide Oxidation, Reduction, and Blocking Agents on Sugar-Snap Cookie Spread and Dough Consistency

To determine whether changes in protein induced within a cultivar affect dough consistency and cookie spread, thiol-disulfide oxidation, cleaving, and blocking agents were added to five pure cultivar soft wheat flours. As discussed earlier, these agents are reported to cause large differences in disulfide bonding and rate of interchange in hard wheat developed glutens. The five cultivars (Adder, Auburn, Becker, Cardinal, and Severn) ranged from 8.1 to 10.4% protein, were all low in AWRC, and had no sprout damage (Table III).

UTM consistency in untreated doughs was lowest in doughs made from Cardinal and highest in doughs made from Severn (Table IV). Severn produced the most cookie spread and Auburn the least. Doughs having higher consistency values are drier feeling, less sticky to roll, and handle more easily. Across treatments, dough consistency was most altered in Severn doughs and least altered in Auburn doughs. Auburn and Severn changed most in cookie diameter, whereas the diameter of Adder cookies changed least.

Potassium iodate, the sulfhydryl oxidizing agent that increases gluten elasticity, significantly lowered the consistency of Severn doughs and significantly increased the diameter of Auburn and Severn cookies. L-Cysteine, the disulfide cleaving agent (which decreases gluten elasticity), did not significantly change the consistency of any one cultivar. It did significantly increase the diameters of cookies made from Auburn, Severn, Becker, and Cardinal wheats. NEMI, which blocks sulfhydryl groups (initially increasing gluten elasticity), significantly increased the consistency of Severn doughs. It significantly increased the diameters of Auburn, Becker, and Severn cookies. Dithioerythritol, the disulfide cleaving agent (which bonds with the resulting disulfide bonds, removing them from further thiol interchange), had the most effect on dough consistency. It reduced the consistency of Cardinal, Becker, Adder, and Severn doughs. It significantly reduced the spread of Severn, Auburn, Cardinal, and Adder cookies.

Analysis of variance of the effects of all treatments and of the effects of cultivar differences on dough consistency and cookie diameter are shown in Table V. UTM consistency of doughs was more affected by cultivar differences than by treatment effects. As mentioned above, treatments were mostly functional at elevated baking temperatures. It is understandable that they had less effect on doughs at room temperature, where consistency measurements were made. However, cookie diameter is the result of the effects of temperature on the dough during baking. Cookie diameter was more affected by chemical treatments than by differences among cultivars. That is noteworthy because cultivar diameters ranged from average to good in this study.

Effects of Dough Liquid Level and Mixing Time on Sugar-Snap Cookie Dough Consistency, Cookie Spread, and Cookie Hardness

Sugar-snap doughs and cookies were produced using two liquid levels and four mixing times from Caldwell and Becker cultivars (Table VI). The liquid levels were below and above optimum, near the limits of acceptable handling. Mixing times were 15, 30, 60, and 90 sec (short, about normal, long, and very long, respectively). Cookie diameter, top grain, and dough consistency changed negligibly with mixing time. Longer mixing times produced cookies that were ranked significantly harder in texture.

Analysis of variance revealed cookie diameter, top grain, and dough consistency were affected more by dough liquid level than by varying dough mixing (Table VII). Cookies were ranked for hardness according to mixing time and not across liquid levels. Therefore, when hardness ranking and diameter were evaluated only against mixing time, mixing time had a stronger influence on cookie hardness ranking than on cookie spread. However, panelists informally reported the higher water level produced obviously harder cookies. LSD values for hardness ranking of cookies made with the higher dough water level were more than double the LSD of the lower liquid level cookies (1.68 vs. 0.75). It appears there were fewer differences or more difficulty distinguishing hardness among the harder cookies.

TABLE IV
Control Values, Degree of Change from Control, and Means for Cookie Diameter and Dough Consistency from Four Protein Treatments for Five Soft Wheat Cultivars

Treatment	Cultivar	Cookie Diameter (cm)	Dough Consistency (kg)
Untreated Control	Adder	17.5	6.4
	Auburn	17.1	6.6
	Becker	17.6	7.1
	Cardinal	17.6	5.7
	Severn	17.7	7.7
Mean		17.5	6.7
Potassium iodate	Adder	−0.1	0.0
	Auburn	+0.4	+0.1
	Becker	−0.1	−0.2
	Cardinal	0.0	−0.1
	Severn	+0.3	−0.5
Mean		17.5	6.5
L-Cysteine	Adder	+0.1	0.0
	Auburn	+0.6	+0.3
	Becker	+0.3	+0.1
	Cardinal	+0.3	+0.2
	Severn	+0.4	−0.3
Mean		17.8	6.7
NEMI[a]	Adder	0.0	+0.2
	Auburn	+0.3	−0.2
	Becker	+0.2	−0.3
	Cardinal	−0.1	+0.2
	Severn	+0.2	+0.6
Mean		17.6	6.7
Dithioerythritol	Adder	−0.3	−0.4
	Auburn	−0.5	−0.2
	Becker	−0.1	−0.7
	Cardinal	−0.4	−0.9
	Severn	−0.7	+0.4
Mean		17.1	6.1
LSD		0.15	0.35

[a] *N*-ethylmaleimide.

TABLE V
Analysis of Variance Mean Squares, *F* Ratios, and Levels of Significance for Cookie Diameter and Cookie Dough Consistency

Source	Mean Square	*F* Ratio	Level of Probability
Treatment			
vs. cookie diameter	0.3708	13.5	0.0000
vs. dough consistency	0.2914	4.4	0.0136
Cultivar			
vs. cookie diameter	0.1090	4.0	0.0203
vs. dough consistency	2.9786	45.1	0.0000

CONCLUSIONS

Across cultivars, correlation coefficients were essentially the same between cookie diameter and protein content and between cookie diameter and mixograph mixing strength. That is likely because mixing strength is usually well correlated with protein content. No significant relationship was found between protein content and mixograph values used in an algorithm to predict cookie diameter (previously reported for protein content and alveograph *P* values, Bettge et al 1989). That suggests the types of measurements used to assess the quality of soft wheat proteins can vary in their correlation with sugar-snap cookie spread. It also suggests that cookie spread itself is less than sensitive to soft wheat protein mixing quality; especially as that quality relates to other product qualities, such as texture.

Cultivars varied in their response to chemical agents, which are often used to alter gluten proteins of hard wheats. There was also no specific pattern of response of dough consistency or cookie diameter to the chemical agents relative to their reported effects (in the literature) on developed gluten. The effects of the agents during baking appeared to be independent of their activity

TABLE VI
Mean Values of Two Cultivars for Cookie Diameter, Cookie Top Grain, Dough Consistency, and Hardness Rankings

Liquid Level (ml)	Mixing Time (sec)	Cookie Diameter (cm)	Cookie Top Grain (score)	Dough Consistency (kg)	Hardness Ranking[a]
6.5	15	17.5	2	3.3	3.9
6.5	30	18.0	3	3.9	3.0
6.5	60	17.4	4	3.6	2.1
6.5	90	17.8	4	3.5	1.0
7.5	15	18.0	5	1.9	3.9
7.5	30	18.2	6	2.1	2.5
7.5	60	18.3	6	1.9	2.4
7.5	90	18.4	7	1.9	1.3
LSD		0.19	0.99	0.298	0.62

[a] Lower ranking indicates harder cookie.

TABLE VII
Analysis of Variance Mean Squares, *F* Ratios, and Levels of Significance for Cookie Diameter, Cookie Top Grain, Dough Consistency, and Cookie Hardness Ranking for Two Cultivars

Source	Mean Square	*F* Ratio	Level of Probability
Cookie diameter			
Liquid level	1.6790	57.3	0.0000
Mixing time	0.1904	6.5	0.0022
Interaction	0.7031	2.2	0.1101
Cookie top grain			
Liquid level	63.2813	39.2	0.0000
Mixing time	6.6146	4.1	0.0176
Interaction	0.4469	0.3	0.8411
Dough consistency			
Liquid level	21.0763	136.8	0.0000
Mixing time	0.2576	1.7	0.1996
Interaction	0.0561	0.4	0.7794
Mixing time			
Cookie hardness ranking	10.4167	125.0	0.0000
Cookie diameter	0.1904	2.1	0.1271

on dough consistency at room temperature. The agents did vary cookie spread more than did the effect of cultivar.

Gluten was not (or was to a very limited extent) produced during the normal mixing of sugar-snap cookie doughs. However, dithioerythritol, which reportedly produces the most change in developed gluten, produced the most change in sugar-snap cookie dough consistency and cookie spread. Those observations suggest that the protein precursors to gluten formation, gliadin and/or glutenin, are functional during cookie baking, even though little, if any, of the gluten network is produced.

A further approach was to increase the association of soft wheat proteins by adding more dough water and increasing mixing time. As discussed in the Introduction, cookie doughs contain too much fat and too little water to produce a developed network of gluten. More dough liquid increased cookie spread, improved top grain, and decreased dough consistency. Longer mixing increased the hardness ranking. Hardness increased even though dough consistency showed no significant increase, as measured by the UTM. Thus, any gluten network developed during mixing sufficient to affect the UTM measurement was relatively small compared with the increase observed in cookie hardness. Sugar-snap cookie hardness was sensitive to increased association of soft wheat proteins.

The contribution of soft wheat flour protein quality to product quality has been little studied. The effects of mixing time and added chemical agents on developed gluten in hard wheat doughs are well known. To the extent that thiol group reactivity defines protein quality, the relatively large changes those treatments caused in sugar-snap cookies and doughs showed that soft wheat protein quality is functional in doughs (at least) after mixing and during baking. The result of that functionality is obviously dissimilar to that of developed hard wheat proteins in bread dough. It is likely that several aspects of soft wheat products are affected by protein quality.

Those findings suggest the theory that some functional association of soft wheat proteins occurs during mixing. Later during baking, more association of proteins probably occurs when the expansion of gas cells forces more increasingly hydrating proteins into sufficient proximity. Thus, besides explaining why sugar-snap doughs stop (if not influence) spreading at the end of the baking period (Doescher et al 1987, Slade et al 1989), soft wheat proteins affect other important quality parameters. Among them are cookie texture and, apparently to a lesser extent, dough consistency.

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