II. Application to Product Quality Variables

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ABSTRACT

A probing technique was used to measure the effects of various treatments on the hardness of cookies produced by two laboratory formulations, the AACC micromethod for sugar-snap cookies and a new formula for wire-cut cookies typical of commercial products. The technique was able to quantify hardness differences associated with wheat cultivar, wheat class blending, quality of ingredients, cookie geometry, wheat test weight, kernel shriveling, crop year, and flour protein content. Higher protein content and more kernel shriveling were associated with harder cookies.

Higher flour protein content resulted in harder wire-cut formula cookies (as is usually observed in commercial baking); however, sugar-snap cookies were thicker and less hard. Probing was also used to evaluate the hardness of cookies produced from two pairs of flours that were fractionated and then reconstituted with one to three fractions interchanged. Fractions that contributed positively to cookie hardness were tailings, gluten, and water-solubles. Fractions appeared to contribute to hardness in the order of their hydrophilicity.

Makers of the great variety of soft wheat products use flour from soft wheat mainly because it produces a more tender, softer, lighter, and larger product than hard wheat flour. The same products made with hard wheats are harder in texture, denser, and smaller and are generally considered inferior by comparison. The availability of instrumental methods for assessing the hardness or softness of soft wheat products should allow better evaluation of and control over the desirable characteristics that soft wheat imparts to products such as cookies.

Perhaps because reliable instrumental techniques for evaluating cookie texture have not been available, the literature contains few reports of variables that affect cookie hardness. The main quality factors that account for the superior performance of soft wheat in traditional soft wheat products are tested for and demonstrated by low water-holding capacity, kernel softness, and low protein content (Yamazaki 1953, 1954; Yamazaki et al. 1968). These characteristics are probably also associated with soft product texture.

Matz (1962) described the texture of cookies as a combined function of the size and shape of the crumb structure, the strength within individual pockets of mostly discrete dough masses, the strength of the contiguous boundaries between those pockets, the moisture content and gradients, and the internal stresses produced during baking and cooling. Commercial bakers often speak of associations between protein content and cookie hardness as well as between wheat class, location of growth, and crop year and cookie hardness.

Gaines (1990) showed that the development of protein content during mixing produces harder cookies. Alteration of cookie dough protein with protease can have dramatic effects on cookie geometry and texture (Gaines and Finney 1989). Crop year and growth location have large effects on alkaline water retention capacity (AWRC), flour protein content, kernel softness (break flour yield), and sugar-snap cookie spread (Finney et al. 1987). Softer-textured wheats with greater break flour yield generally produce cookies with more spread (Gaines 1985, Gaines and Donelson 1985).

Wheat test weight (weight per unit volume) has long been used as a market quality indicator. Historically, lower test weight has been purported to predict lower potential flour yield. Shriveling is one of several factors that lower wheat test weight. Because shriveled grain is more irregular in shape than sound, plump grain, it packs less densely in a volume cup, lowering test weight. Shriveled grain also reduces flour yield (Patterson and Allan 1981, Dick and Matsuo 1988). Test weight only in part reflects the degree of shriveling.

Formulation differences in sugar-shortening ratio can markedly influence cookie geometry (Finney et al. 1950) and presumably cookie texture. Changing the particle size of formula sucrose is especially effective in altering cookie geometry (Kissell et al. 1973).

Many variables probably affect the hardness of cookies. Fractionation-reconstitution can be used to study the effects of flour, dough, and product treatments. This technique has been used to study the effects of chlorination on cookie flour (Donelson 1990) and cake flour (Gaines and Donelson 1982) and may have potential for cookie texture studies.

Although cookie texture affects consumer acceptance and repeat sales, the evaluation of cookie texture is often too expensive and time-consuming to be routinely included in quality assurance and cultivar quality evaluation programs. Gaines et al. (1992) evaluated probing and three-point break techniques for instrumental measurement of the hardness of cookies made from three laboratory formulations, the AACC micromethod and macromethod for sugar-snap cookies (AACC 1983) and a formulation for wire-cut cookies (Slade and Levine in press). The wire-cut formula cookies usually had less variance for the range of hardness evaluated than the sugar-snap cookies. Gaines et al. (1992) concluded that the combination of the wire-cut formulation for laboratory cookie production with the probing test for hardness measurement has impressive potential for improving the quality and consistency of commercial cookies and for the prediction of soft wheat quality.

In this study, we attempted to apply the probe technique to evaluate a range of baking, product, and flour quality variables that likely cause textural hardness differences in cookies, including wheat class blending, wheat cultivar, wheat kernel quality (size, test weight, and shriveling), baking formulation, quality of ingredients, protein content, and product geometry. In addition, we continued to evaluate the new laboratory wire-cut cookie formulation of Slade and Levine (in press).

MATERIALS AND METHODS

Order of Studies and Wheats

The use of the probing technique for evaluating cookie hardness was demonstrated in ten studies. The first study assessed the effects of the quality of shortening and high-fructose corn syrup (HFCS) on the hardness of cookies made with flour from the cultivar Becker (1989 crop). The second study investigated the differences in hardness of cookies made from commercial versus laboratory quality ingredients. In the third study, the effects on cookie hard-ness of mill mix blending were studied for two pairs of flours produced from milling a blend of soft and hard wheats.

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The fourth study demonstrated the influence of cookie geometry (diameter and height) on hardness of cookies made from 22 flours from laboratory and commercial sources. The fifth study showed associations between wheat test weight and cookie hardness for six soft red winter cultivars (Frankenmuth, Auburn, Hillsdale, Lewjain, Nugaines, and Dawes) grown at two locations.

The sixth study investigated the influence of kernel size on cookie hardness. The cultivar Titan (35 kg) was separated into three portions based on kernel size with a Carter-Day dockage tester. The large kernels (11%) were retained through 3.6-mm holes, the medium-size kernels (86%) passed through 3.6-mm holes but were retained over 2.8-mm holes, and the small kernels (3%) passed through 2.8-mm holes.

The seventh study demonstrated the association of kernel shirveling and cookie hardness. Kernels of the cultivar Becker were hand-separated into one sample with only sound, unshirveled kernels, another sample with only shirveled kernels, and a third sample containing 50% (by weight) shirveled kernels, obtained by mixing portions of the first two samples.

The eighth study used four samples of one cultivar (Caldwell) grown at one location to demonstrate the influence on cookie hardness of variations in flour protein content within a cultivar. The ninth study investigated the implications of crop year differences for hardness of cookies made from two sets of four flours (cultivars Caldwell, Hillsdale, Becker, and Compton) from two crop years (1988 and 1989) milled at the same commercial mill.

In the final study, we fractionated flours from the cultivars Becker and Compton (1988 crop) and Becker and Caldwell (1989 crop) and tested cookies made from reconstituted flours with one to three fractions interchanged to demonstrate the relative contributions to cookie hardness of fractions from flours that make relatively hard and soft cookies.

**Milling**
Except for the ninth and tenth studies, pure cultivars were milled on an Allis-Chalmers laboratory mill (AAC 1983, method 26-32). Breeders’ samples were milled using tandem Brabender Jr. Quadrumat mills. Other flours were obtained from commercial mills. Flour protein (AAC 1983, method 46-12), ash (method 08-01), AWRD (method 56-10), wheat test weight (method 55-10), and alveograph values (method 54-30) were determined.

**Baking and Hardness Testing**
Sugar-snap cookies were made as directed in the AACC micro-method (AAC 1983, method 10-52) for the evaluation of cookie geometry. Wire-cut formula cookies were produced by the method of Slade and Levine (in press), as described by Gaines et al (1992). All baking experiments were replicated on different days.

Products were probed for hardness with an Instron model 1000 universal testing machine by the method of Bourne (1975, 1990), as described by Gaines et al (1992). Cookie hardness was always evaluated two days after baking.

**Flour Fractionation and Reconstitution**
Two pairs of flours (cultivars Becker and Compton from the 1988 crop and Becker and Caldwell from the 1989 crop) were each fractionated into starch, lipid, tailings, gluten, and water-solubles (Yamazaki et al 1977). Because preliminary investigations showed that the particle size of reconstituted flours affected cookie texture, the lyophilized starch, tailings, gluten, and water-solubles were further ground so that the reconstituted blends of fractions had a mean particle size (AAC 1983, method 50-11) equivalent to that of the unfractionated flours. When this was done, cookies produced from reconstituted flours (without fraction interchanges) were indistinguishable in hardness ($P = 0.05$) from cookies made from the original unfractionated flours, as determined by ranking order difference sensory evaluation as described by Gaines et al (1992). Fractions were recombined into flours with single or multiple fraction interchanges. The hardness of wire-cut formula cookies produced from each recombined flour was evaluated by the instrumental resistance to probing.

**Statistical Analysis**
Each cookie was probed 13 times, and the mean hardness value was recorded. Four cookies were evaluated per treatment. Data were analyzed by analysis of variance ($n=4$) and linear regression. Tabulated means were compared by the least significant difference statistic at the 0.05 level of probability.

**RESULTS AND DISCUSSION**
Gaines et al (1992) concluded that probing and three-point break techniques could be used to evaluate the hardness of cookies made from two sugar-snap formulations and a wire-cut formulation. The probe technique and the wire-cut formulation were desirable as laboratory procedures. To be most useful to potential users, the probe technique should be sensitive to a wide range of product, baking, wheat, and flour quality variables that affect product hardness. Our studies evaluated a number of these variables.

**Study 1: Shortening and HFCS**
The type of shortening affects the quality of commercial cookies. Age-related changes in shortening condition also may affect product quality. Older shortening can “weep” oil from the more crystalline material. We replaced a cube of aged, weeping shortening with a newer cube of the same shortening. We also replaced an old container of HFCS that had begun to “cloud” with a new one. In commercial bakeries, HFCS is normally used before it clouds; however, whether clouding would affect cookie texture was unknown.

Table 1 shows the hardness of wire-cut formula cookies made with old and new HFCS and shortening. Both syrups had the same effect on the resistance of the cookies to probing. However, cookies made with the new shortening were harder, thicker, and smaller in diameter than those made with the old shortening.

**Study 2: Ingredients**
Commercial and laboratory baking method ingredients can have disparate qualities. Figure 1 shows the difference in the hardness of wire-cut formula cookies made from eight flours with commercial ingredients (commercial bakery sucrose, brownulated granulated brown sugar, and shortening) versus laboratory ingredients (a finer granulation sugar, powdered brownulated brown sugar, and a different brand of shortening). Cookies made with the laboratory ingredient substitutions were less hard than those made with the commercial ingredients. The mean difference in hardness was 11 N. The hardness values for the eight flours were well correlated ($r = 0.91$) between both sets of ingredients.

**Study 3: Mill Mix Blends**
Two pairs of flours were commercially milled from blends of soft and hard wheats. One pair was produced from a blend of 60% western soft white club and 40% hard red winter wheat from Montana or hard red winter wheat from Kansas. The other pair was produced from a blend of 80% eastern soft red winter wheat and 20% hard red winter wheat from Montana or hard red winter wheat from Kansas. For both soft wheat-based blends, replacing the hard red winter wheat from Montana (protein 13.3%) with the softer western soft white club (protein 11.7%) produced a significant decrease in hardness ($P = 0.05$).

**TABLE 1**

<table>
<thead>
<tr>
<th>Shortening</th>
<th>HFCS</th>
<th>Diameter (cm)</th>
<th>Height (cm)</th>
<th>Probe Resistance (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old</td>
<td>Old</td>
<td>8.58 a</td>
<td>0.910 b</td>
<td>21.9 b</td>
</tr>
<tr>
<td>Old</td>
<td>New</td>
<td>8.58 a</td>
<td>0.912 b</td>
<td>20.8 b</td>
</tr>
<tr>
<td>New</td>
<td>Old</td>
<td>8.26 b</td>
<td>0.967 a</td>
<td>23.5 a</td>
</tr>
<tr>
<td>New</td>
<td>New</td>
<td>8.26 b</td>
<td>0.976 a</td>
<td>23.5 a</td>
</tr>
</tbody>
</table>

*Means within a column followed by the same letter are not significantly different ($P = 0.05$). Probe was 4.5 mm in diameter. Crosshead speed was 300 mm/min.

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alveograph work number 381) with the hard red winter wheat from Kansas (protein 11.8%, alveograph work number 209) produced softer wire-cut formula cookies with more spread (Fig. 2). Figure 2 also reflects the observation that soft white club wheats often produce harder cookies than do soft red winter wheats. Neither the flour protein content nor the mixing strength (as estimated by the alveograph work number) was well correlated with cookie hardness or diameter. Wheat class and location of growth were the predominant influences on cookie hardness and spread.

Study 4: Cookie Geometry
Another common observation in commercial baking is that higher flour protein content and harder kernel texture (less break flour) are associated with smaller, thicker, and harder cookies. The data in Figure 2 also show that smaller-diameter wire-cut formula cookies were harder. But when flour with elevated protein content is used in the two AACC sugar-snap cookie methods, which were formulated to produce large spread, cookies are smaller and thicker but softer. Figure 3 shows the association between cookie diameter, thickness, and probe resistance for sugar-snap cookies made from 22 flours by the AACC micromethod. In contrast to wire-cut formula cookies (Fig. 2), the smaller, thicker micromethod cookies tended to be less hard. This opposite response suggests that sugar-snap cookies may be of limited use in studying cookie texture relative to commercial experience. These findings are currently being investigated further.

Study 5: Wheat Test Weight
Six soft wheat cultivars were each grown in two locations, resulting in differences in wheat test weight, protein content, and shriveling. Samples with lower test weight (from location A) were higher in protein and in break flour yield (had softer kernels) and produced harder micromethod cookies than samples from location B (Fig. 4). Samples from location A also had smaller kernels and considerable shriveling.

Study 6: Kernel Size
Shrived kernels are usually higher in protein than unshrived kernels, but they are also smaller. Shriving usually results in lower test weight. We examined these relationships within two cultivars rather than between cultivars. First, plump, sound kernels of the cultivar Titan were sieved into large, medium, and small kernels. The size of sound kernels did not have a statistically significant effect on wire-cut formula cookie resistance to probing, cookie size, flour ash, flour protein, or AWRC (Table II).

Study 7: Kernel Shriving
A sample of cultivar Becker was hand-separated into one portion containing all sound, unshrived kernels, one containing all highly shrived kernels, and one containing half (by weight) shrived kernels. A greater proportion of shrived kernels resulted in harder, smaller, thicker cookies and was also associated with increased flour protein, ash, and AWRC (Table III). Again, thicker wire-cut formula cookies were also harder. Shriving results in less accumulated starch and a higher rela-
tive protein content. However, the relationship between protein content and shriveling may not be one of cause and effect. In our studies, shriveled kernels (not smaller kernels) produced higher-protein flours and harder cookies. The higher protein content of the shriveled samples probably influenced cookie hardness, but the increase in protein (0.6 percentage points) was probably not the sole cause of the 4.7 N increase in probe resistance. This suggests that another aspect of shriveled kernels may influence product texture and/or that protein quality may be different in shriveled kernels.

**Study 8: Protein Content**

Wire-cut formula cookies were produced from four samples of cultivar Caldwell grown at one location and varying in protein content. Probe resistance increased 5 N as protein content increased 3.1 percentage points (Table IV). As protein content increased, cookie spread was only slightly reduced and thickness was only slightly increased. The regression equation of the relationship between protein content (PC) and probe resistance (PR) was: 

\[ PR = 1.67(\text{PC}) + 7.41 \]  

\( R^2 = 0.97 \). Within the range of the study, probe resistance increased approximately 1.7 N (8.5%) for each percentage point increase in protein content.

**Study 9: Crop Year**

Table V shows another example of the relation between cookie hardness and flour protein content both within and across cultivars. Four cultivars from the 1988 and 1989 crop years were evaluated. On average, 1989 samples had less protein (1.5 percentage points), yielded more break flour (8.7 percentage points), and produced softer cookies (4.5 N) than 1988 samples.

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**TABLE III**

| Shrivel (%), Probe Resistance (N), Cookie Diameter (cm), Cookie Height (cm), Flour Ash (%) | AWRC (%) |
|---|---|---|---|---|
| 0 | 25.3 a | 8.2 a | 1.02 b | 0.40 a |
| 50 | 27.2 b | 7.8 b | 1.10 a | 0.42 a |
| 100 | 30.0 c | 7.8 b | 1.15 a | 0.45 b |

*Means within a column followed by the same letter are not significantly different (P > 0.05).

*Alkaline water retention capacity.

**TABLE IV**

<table>
<thead>
<tr>
<th>Protein Content (%)</th>
<th>Probe Resistance (N)</th>
<th>Cookie Diameter (cm)</th>
<th>Cookie Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
<td>19.2 a</td>
<td>8.0 a</td>
<td>1.00 a</td>
</tr>
<tr>
<td>8.1</td>
<td>20.3 a</td>
<td>7.9 b</td>
<td>1.04 b</td>
</tr>
<tr>
<td>9.0</td>
<td>22.5 b</td>
<td>7.9 b</td>
<td>1.05 b</td>
</tr>
<tr>
<td>10.0</td>
<td>24.3 c</td>
<td>7.8 c</td>
<td>1.06 b</td>
</tr>
</tbody>
</table>

*Means within a column followed by the same letter are not significantly different (P > 0.05).

**TABLE V**

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Probe Resistance (N)</th>
<th>Protein Content (%)</th>
<th>Break Flour (%), 1988 Crop</th>
<th>Probe Resistance (N)</th>
<th>Protein Content (%)</th>
<th>Break Flour (%), 1989 Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caldwell</td>
<td>24.4</td>
<td>9.3</td>
<td>30.4</td>
<td>15.9</td>
<td>7.7</td>
<td>39.2</td>
</tr>
<tr>
<td>Hillsdale</td>
<td>22.1</td>
<td>10.8</td>
<td>25.8</td>
<td>18.8</td>
<td>8.3</td>
<td>34.6</td>
</tr>
<tr>
<td>Becker</td>
<td>29.0</td>
<td>10.1</td>
<td>28.6</td>
<td>22.1</td>
<td>6.9</td>
<td>39.2</td>
</tr>
<tr>
<td>Compton</td>
<td>22.5</td>
<td>8.6</td>
<td>25.3</td>
<td>23.1</td>
<td>10.0</td>
<td>31.6</td>
</tr>
<tr>
<td>Mean</td>
<td>24.5</td>
<td>9.7</td>
<td>27.5</td>
<td>20.0</td>
<td>8.2</td>
<td>36.2</td>
</tr>
</tbody>
</table>

*All differences between crop years were significant (P < 0.05) except for Compton probe resistance.

Fig. 4. Probe resistance (Instron force), break flour yield, and protein content of six soft wheat cultivars (square, Frankenmuth; diamond, Auburn; triangle, Hillsdale; bottom-filled circle, Lewjain; side-filled circle, Nugaines; filled circle, Dawn) grown in two locations.
changed when flour pairs were reconstituted. Differences in
hardness of the pairs of cookies made from the interchanged
reconstituted flours were measured with the probe technique
and compared with differences between the control reconstituted flours
with all original flour fractions (no fractions interchanged). A
fully effective interchange would be one that completely reversed
the difference in hardness between the original hard and softer
cultivars; that is, the difference in probe resistance would be the
same in magnitude but opposite in sign. A lesser than complete
shift, from positive to less positive or to negative differences
between the pairs, indicated that the interchanged fractions
contributed to hardness.

In the first fraction interchange, between 1988 cultivar Becker,
which produced harder cookies, and 1988 cultivar Compton,
which produced softer cookies, interchanging the starch fraction
had the least effect on the difference in hardness of wire-cut
formula cookies, 1989 cultivar in increasing order by lipid, tailings,
gluten + tailings, gluten, water-solubles, gluten plus tailings, gluten plus water-
solubles, and gluten plus water-solubles plus tailings (Fig. 5A).
In the second fraction interchange, between 1989 cultivar Becker,
which produced harder cookies, and 1989 cultivar Caldwell,
which produced softer cookies, an additional fraction combination,
water-solubles plus tailings, was added. The lipid fraction contrib-
uted the least to cookie hardness, followed in increasing order
by starch, gluten plus tailings, gluten, tailings, gluten plus water-
solubles, water-solubles, water-solubles plus tailings, and gluten
plus water-solubles plus tailings (Fig. 5B). Except for the greater
effectiveness of the tailings and water-solubles, these results
generally corroborated the results of the Compton-Becker
interchange.

The relative effectiveness of interchanging combinations of two
or three fractions was generally predictable from the effectiveness
of interchanges of the individual fractions. For example, note
in Figure 6 that the combination of water-solubles plus tailings
was more effective than water-solubles plus gluten, because the
tailings fraction was more effective than the gluten fraction. Differences
in hardness were fully reversed when the three most indi-

dividually effective fractions (water-solubles, tailings, and gluten)
were interchanged.

The order of effectiveness of fraction interchanges corresponded
to the order of hydrophilicity of the fractions: water-solubles are
most hydrophilic, followed in decreasing order by tailings, gluten,
starch, and lipid. This suggests that the hydrophilicity or lack of
it (hydrophobicity) of the fractions, rather than or in combina-
tion with inherent or native-state chemical or physical contribu-
tions, could have governed their respective effectiveness in each
interchange. It is likely that biochemical and biophysical con-
tributors to product hardnes require hydration to the extent they
normally achieve (if known) in their native, unfractonated state.
If so, fractionation and reconstitution studies may be less effective
as research tools than evaluations of the hydrophobic-hydrophilic
relationships of flour components. These issues are currently being
studied further.

CONCLUSIONS

Wire-cut formula cookies, like commercial cookies, tended to
be harder when they were smaller and thicker; sugar-snap cookies,
by contrast, tended to get softer as they got smaller and thicker.
Thus, sugar-snap cookies may have limited value in studies
concerned with treatments that alter cookie texture.

A probe technique for measuring cookie hardness was used
to investigate a range of wheat, flour, baking, and product
variables that affect the hardness of cookies. Probing could
measure differences in cookie hardness due to wheat cultivar,

cultivars, class blending, ingredients, shortening age, kernel
shrivelng, flour protein content, and the various contributions
of crop year (or break flour). Shrived kernels and increased
protein content were most strongly associated with harder cookies.
Combinations of cultivar, crop year, and protein content may
be major determinants of cookie hardness, and are currently being
investigated further. Interchanged flour fractions contributed to
cookie hardnes in an order corresponding to their hydrophilicity.

Water relations appear to be a factor in cookie texture, at least
in addition to the biochemical and biophysical contributions of
flour components.

Our results suggest that the hardness of commercial cookies
could be controlled more consistently by controlling cultivar,
protein content, and kernel shrivelng. The combination of the
wire-cut formulation for laboratory cookie production with
probing for hardness measurement was demonstrated to be sensi-
tive enough to hardness differences to be useful in the evaluation
and prediction of soft wheat cultivar and flour quality.

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