Instrumental Measurement of Cookie Hardness. I. Assessment of Methods

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ABSTRACT

Probing and a three-point break technique for instrumental measurement of cookie hardness were appraised. Both techniques were used to evaluate the hardness of cookies produced by three laboratory formulations: the AACC micromethod and macromethod for sugar-snap cookies and a new commercial formula for wire-cut cookies. The three formulas differ in their ratios of sugar, shortening, and water. Both instrumental and sensory measurements indicated that wire-cut formula cookies were the least hard of the three formulations. The three-point break technique measured both hardness and brittleness, but the probe technique required less product. Probing was used to assess differences among four wheat cultivars and effects of postbake age on cookie hardness. Least significant differences and variances for probing data (as a percentage of the range of hardness observed with the four cultivars) were usually smallest for the wire-cut formula cookies.

Texture is an important element of cookie quality. It affects consumer acceptance and repeat sales. Flour millers, product developers, bakers, and cultivar quality evaluators would benefit from the development of instrumental techniques for measuring cookie texture that were based on reproducible and statistically sound principles of materials testing. Gaines (in press) reviewed many examples of theoretically sound principles of materials testing that are applicable to cookies and crackers.

Probe testing is one technique of interest. According to Bourne (1982, 1990a), probing should have much wider application to cereal-based foods such as cookies and crackers. Probing is also known as penetrating, puncturing, and punching, depending on the product tested and the degree of penetration. The results are given various interpretations, including firmness, toughness, tenderness, ripeness, and hardness, again depending on the product (Szczesniak 1972). The technique usually measures the maximum force required to push a probe into or through a product. The depth of penetration is sometimes recorded as the hardness value.

A snapping technique—known as the three-point break, triple-beam snap, or snap test—is also used to evaluate hardness and brittleness of cookies. Two beams a known distance apart support the product. Another beam is brought down to touch the product at a point equidistant from both support beams. Slow downward movement of the top beam is continued, causing some degree of deformation of the product before it breaks (snaps). The slope and peak force at break recorded on a strip chart are used to estimate product brittleness and hardness, respectively. The slope often is referred to as Young's modulus. In general, except for very brittle products, the less the deformation before breaking, the more brittle the cookie. An estimate of snapping force also can be calculated (described below). The snapping force for most shapes of cookies is inversely proportional to the space between the two support beams and directly proportional to product width and to the square of product thickness (Bourne 1982).

In this study, probing and three-point break methods were applied to assess hardness and hardness and brittleness, respectively, of cookies made from three formulations, a new wire-cut formulation from Slade and Levine (in press) and the two AACC sugar-snap cookie methods (AACC 1983). The effects of instrument variables, baking formulation, and postbake time on the hardness of cookies made from four cultivars were evaluated. Data from the probe technique were compared with sensory panel rankings of the hardness of cookies produced from the three formulations.

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MATERIALS AND METHODS

Wheats

Four commercially milled cultivars (Caldwell, Hillsdale, Becker, and Compton) were evaluated. Table I shows the break flour yield (AACC 1983, method 26-32), flour protein content (method 46-12), flour ash content (method 08-01), flour particle size (method 50-11), damaged starch (Donelson and Yamazaki 1962), and alkaline water retention capacity (method 56-10) for each cultivar.

Baking

Sugar-snap cookies were produced according to AACC methods 10-50D (macromethod) and 10-52 (micromethod) (AACC 1983). Wire-cut formula cookies were produced from the formulation of Slade and Levine (in press). The ingredient formulations are given on a 100-g flour basis in Table II.

The procedure adapted from Slade and Levine (in press) is as follows. Dry ingredients for the number of batches plus one were weighed and transferred into a gallon (3.8 L) jar. The jar was tumbled 20 times to mix the dry ingredients. Shortening for the number of batches plus one was weighed into a 10-qt (9.5 L) mixing bowl. Dry ingredients were added to the shortening and mixed for 3 min on speed 1; the sides of the bowl were scraped each minute. For each dough, 191.9 g of the creamed mass was scraped into a 3-qt (2.8 L) mixing bowl. Then 3.4 g of high-fructose corn syrup (HFCS) was weighed into a 250-ml beaker, and the appropriate amount of dough water was added and swirled. (The amount of water was calculated in grams as 274.5 minus grams of flour [13% mb].) Ammonium bicarbonate (1.10 g) was added to the HFCS-water mixture, and the mixture was swirled to dissolve the ammonium bicarbonate. That liquid was added to the creamed mass. The mixture was mixed for 1 min on speed 1, the bowl was scraped, and the mixture was mixed for 1 min on speed 2. The calculated amount of flour was added, and the mixture was mixed for 2 min on speed 1, with scraping every 30 sec.

The dough was gently scraped from the bowl and divided into eight relatively equal portions. Handling the dough as little as possible, we gently rounded the portions and formed them into oblong shapes approximately 5 cm long. Four portions were placed on each of two ungreased baking sheets, with the longer side perpendicular to gauge strips 7 mm (0.275 in.) thick. Doughs were rolled to thickness with only one stroke of a rolling pin. They

TABLE I
Wheat and Flour Quality Values for Four Soft Wheat Cultivars

Cultivar	Break Flour (%)	Flour Protein (%)	Flour Ash (%)	Particle Size (μm)	Damaged Starch (%)	AWRC[a] (%)
Caldwell	30.4	9.3	0.40	49.0	3.2	55.0
Hillsdale	25.8	10.8	0.54	55.5	4.1	54.6
Becker	28.6	10.1	0.43	48.8	3.0	56.7
Compton	25.3	8.6	0.49	52.3	3.9	57.0

[a]Alkaline water retention capacity.

were cut with a cookie cutter (60-mm i.d.). Excess dough was discarded. Cookies were immediately baked in a 205°C (400°F) oven for 11 min, removed from the oven, cooled 5 min, and then removed from the baking sheet.

All baking experiments were replicated on different days. Each replication contained enough doughs (bakes) of each method to produce the quantity of cookies needed for instrumental and sensory evaluations.

Instrumental Measurements

Probing. Cookies were probed for hardness according to the method of Bourne (1975, 1990b) with the blunt (machined flat) ends of drill bits of various sizes. The drill bits were secured in a drill chuck attached to an Instron model 1000 universal testing machine (UTM). Products were placed on an aluminum plate 0.5 in. (1.3 cm) thick with a 0.25-in. (0.6 cm) hole for accepting the bit as it traveled through the cookie. Under the plate, a chamber 2 in. (5.1 cm) in diameter and 0.25 in. (0.6 cm) thick was centered on the hole to catch cookie crumbs. The plate was keyed to fit in the same place on the permanent UTM evaluation bench after it was raised to remove accumulated crumbs.

Cookies were punched through completely. Peak force resistance during probing was recorded as the apparent hardness of the cookie. Probe (bit) size and UTM crosshead speed (deformation rates) were varied for some studies, but unless otherwise stated, wire-cut formula, macromethod, and micromethod cookies were evaluated with 4.5-mm, 3.5-mm, and 2.0-mm probes, respectively, at a crosshead speed of 300 mm/min. Thirteen holes per cookie were punched in an X pattern: one in the center, four at half-radius, four midway between the center and half-radius, and four midway between the edge and half-radius. Except for the studies that evaluated the effects of postbake time (when cookies were evaluated one, two, and three days after baking), all cookies were probed two days after baking.

Coefficients and constants were determined from data plots of resistance to probes with four diameters (Bourne 1966, 1975). Area-dependent and perimeter-dependent coefficients and a constant fit the following equation:

$$F = K_a \cdot A + K_p \cdot P + C \,,$$

where F is the peak puncture force at yield point, A and P are the area and perimeter of the probe, respectively, K_a and K_p are the area-dependent and perimeter-dependent coefficients, respectively, of the product, and C is a constant that is close to zero for most foods. Area- and perimeter-dependent coefficients are related to compression and shear forces, respectively.

Three-point break. Peak force (resistance at break), modulus of deformability (time to peak), and Young's modulus (slope of the curve to peak) were determined from the strip chart trace of the force-deformation curve. In addition, snapping force (F) was calculated as follows:

$$F = (2/3\sigma b h^2)/L \,,$$

where σ is the maximum force at failure, b is the width of the product, h is the thickness of the product, and L is the distance between the bottom supports. The three-point break procedure was performed with a UTM crosshead speed of 10 mm/min. The distance between the two bottom supports was adjusted to one-third of the cookie diameter. Eight cookies per cultivar were tested.

Sensory Assessments

Cookies made from each of the four cultivar flours were randomized and coded for each sensory panel session. Each session included eight to 15 untrained panelists (aged 18–61). Panelists were laboratory personnel who were experienced in ranking the hardness of several commercial products from another study that used the same methods and procedures. In the other study, the mean product hardness rankings of the laboratory panelists corresponded with the rankings of a commercial bakery sensory panel and a university panel. Panelists were selected by their ability to evaluate rankings of duplicate samples.

Panelists were asked to rank cookies on the basis of hardness only on a scale of one (hardest) to four (least hard). They were instructed to evaluate perceived hardness during the first few bites. Incisors and molars could be used. Panelists were told to ignore edge effects on hardness and to use all the remaining sample. Each panelist ranked the hardness of one set of four cookies (from the four cultivars) replicated daily. Panelists evaluated one or more cookies of each cultivar placed on white plates with the code numbers. Cookies were served at room temperature in a laboratory open area. Cups of water were provided. Cookies were evaluated two days after baking.

Statistical Analyses

For the probing studies, each cookie was probed 13 times, and the mean hardness value was recorded. Four cookies (n=4) were evaluated per treatment or cultivar. For the three-point break study, eight cookies (n=8) were evaluated. Analysis of variance was performed, and the coefficient of variation and standard deviation were calculated. Means were compared by the least significant difference (LSD) statistic at the 0.05 level of probability.

TABLE II
Ingredients and Characteristics of Cookies Produced from Three Formulas

Ingredients[a] and Characteristics	AACC Micromethod[b]	AACC Macromethod[c]	Wire-Cut Formula[d]
Flour, g	100.0	100.0	100.0
Shortening, g	30.0	28.4	40.0
Sucrose, g	60.0	57.8[e]	42.0[f]
Salt, g	0.45	0.93	1.24
$NaHCO_3$, g	1.80	1.11	1.02
NH_4Cl, g	0.50	...	...
$(NH_4)_2CO_3$, g	...	...	0.49
Nonfat dry milk, g	3.0	...	1.02
HFCS[g]	...	...	1.51
Water, g	17.5 variable	21.8	22.9
Typical cookie diameter, cm	9.0	8.3	8.3
Water, % of wire-cut	76.5	95.2	100.0
Shortening-water ratio	1.76	1.30	1.75
Sugar-water ratio	3.41	2.65	1.84
Sugar-shortening ratio	2.0	2.0	1.0

[a] On a 100-g basis.
[b] Method 10-52 (AACC 1983).
[c] Method 10-50D (AACC 1983).
[d] Slade and Levine (in press).
[e] Includes 0.8 g of dextrose.
[f] Includes 10.0 g of brown sugar (sucrose).
[g] High-fructose corn syrup.

RESULTS AND DISCUSSION

Three Cookie Formulations

AACC method 10-52 produces two cookies from 40 g of flour and is considered a micromethod. The other two methods use 225 g of flour and are considered macromethods. The micromethod formulation has the highest sugar-water ratio and the lowest percentage of water (Table II), which contribute to larger cookie diameter. The wire-cut formula has the lowest sugar-shortening ratio and the most water. According to Slade and Levine (in press), the lower sugar concentration allows freshly baked wire-cut formula cookies to cool to room temperature without sucrose passing through a glass transition. Because sucrose remains in the crystalline state rather than the much harder glass state, cookies produced from the wire-cut formulation are less hard and brittle.

Compression and Shear Coefficients

The probing technique generated compression (K_a) and shear (K_p) coefficients. K_a is a function of the area of the probe surface that generates compression forces during probing, and K_p is a function of the perimeter (circumference) of the probe that is associated with shear forces produced during probing. Coefficients for cookies produced by the three methods are listed in Table III.

For the micromethod and the wire-cut formulation, the larger values of K_a compared to K_p show that compression forces contribute more than shear forces to probe resistance. The relative magnitude of the coefficients reflects the open, hard crumb structure of AACC micromethod cookies; the micromethod cookies are harder (larger coefficients). The highly negative value of K_a for the micromethod probably reflects the relatively brittle texture of these cookies, which are formulated to develop "snap" upon aging for two to three days. That brittleness may introduce some nonlinearity in the puncture force equation, as indicated by the slightly negative (−2.5) value for the constant. The wire-cut formula cookies are less hard and brittle, and the AACC macromethod cookies are intermediate in hardness. These results show that K_a and K_p appear to differentiate the hardness of cookies made from the three formulations.

Probe Diameter and Deformation Rate

As the probe diameter increased from 3.0 to 4.5 mm, maximum force values (probe resistance) increased for wire-cut formula cookies (Fig. 1). This suggests that the largest probe size that does not crack or break the product can be employed. Also, as probe diameter increased, coefficient of variation percentages tended to decrease (Fig. 2). Faster deformation rates decreased maximum force values and increased the coefficients of variation; however, faster deformation rates are more practical in the laboratory. For most studies, we preferred and selected the largest probe size that did not break the product and a deformation rate of 300 mm/min.

Edge effects probably influence the hardness of all types of baked products. Because cookies in this study were noticeably different in hardness past the outer 15% of their radius, that portion of the cookies was avoided during probe and sensory tests.

TABLE III
Compression and Shear Coefficients[a] for AACC Micromethod, AACC Macromethod, and Wire-Cut Formula Cookies

Formula	Area-Dependent Coefficient (K_a) ($N \cdot cm^{-2}$)	Perimeter-Dependent Coefficient (K_p) ($N \cdot cm^{-1}$)	Constant (C) (N)
AACC micromethod	−127.8	49.6	−2.5
AACC macromethod	2.8	32.8	0.0
Wire-cut formula	51.7	12.2	0.0

[a] Probe sizes for determing coefficients and constants were 2.5, 3.0, 3.5, and 4.0 mm for the wire-cut formula and AACC macromethod and 1.5, 2.0, 2.5, and 3.0 mm for the AACC micromethod.

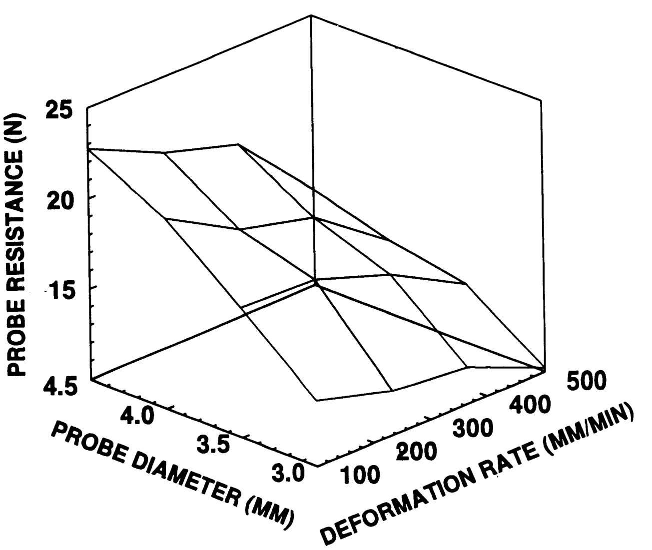

Fig. 1. Effects of probe diameter and deformation rate on resistance to probing of wire-cut formula cookies.

Probe Resistance and Sensory Panel Rankings

Cookies produced from the four cultivars by each of the three methods were ranked for hardness by sensory panels and by probing tests at a slow (20 mm/min) and fast (300 mm/min) deformation rate. Individual panelists' rankings do not indicate the magnitude of difference in hardness among cookies from the four cultivars. However, the panel's mean ranking and degree of standard error often reflect the relative hardnesses. For example, mean rankings of 2.9 and 3.1 indicate that the hardness of cookies made from cultivars individually ranked as 3 and 4, respectively, were very close, with panel members ranking them either 2, 3, or 4.

Mean panel rankings for micromethod cookies (Fig. 3A) were not significantly different for the cultivars Hillsdale and Compton, which agreed with instrumental findings (probe resistance values). That is, neither instrumental probing measurements nor sensory panels could distinguish a statistically significant difference between the hardness of micromethod cookies produced from these cultivars. Mean panel hardness rankings were lower (indicating greater hardness) for cookies made from cultivar Becker than for those made from Hillsdale or Compton. LSD values for the probe resistance data at deformation rates of 20 and 300 mm/min were 63 and 67%, respectively, of the hardness range of the four cultivars, and mean square variances were 91 and 51%, respectively, of the hardness range.

The mean sensory rankings of the macromethod cookies (Fig. 3B) were closer to integer values. Mean instrument values again showed that Hillsdale and Compton produced macromethod cookies with statistically similar hardness. LSD values for the probe resistance data at deformation rates of 20 and 300 mm/min were 22 and 46%, respectively, of the hardness range of the four cultivars, and mean square variances were 41 and 110%, respectively, of the hardness range.

The mean sensory rankings for the wire-cut formula cookies (Fig. 3C) revealed that Compton produced the least hard cookies with this formulation. Probing data indicated that wire-cut cookies produced from Hillsdale and Compton did not differ statistically in hardness. That is, the instrumental data did not show the hardness differences between either wire-cut or macromethod cookies made

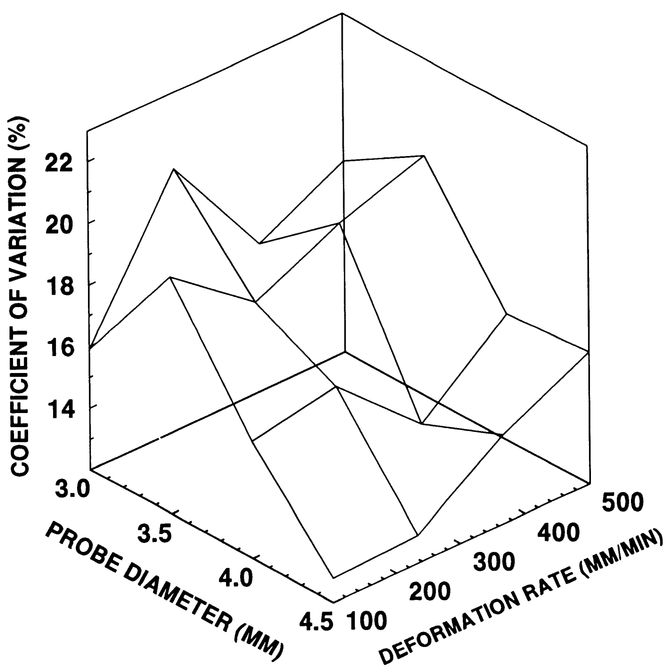

Fig. 2. Effects of probe diameter and deformation rate on coefficient of variation of probing data for wire-cut formula cookies.

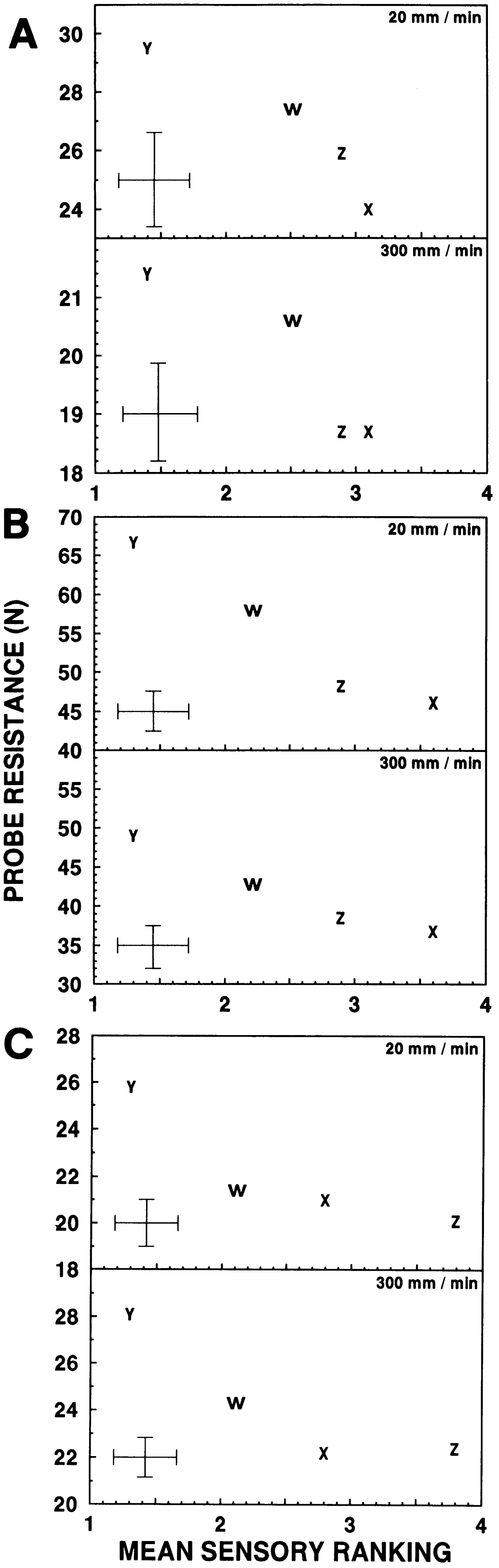

Fig. 3. Mean sensory rankings and instrumental probe resistance values at instrumental deformation rates of 20 and 300 mm/min for AACC micromethod (**A**) and macromethod (**B**) sugar-snap cookies and wire-cut formulation cookies (**C**) made from soft wheat cultivars Caldwell (W), Hillsdale (X), Becker (Y), and Compton (Z). Crossed error lines indicate LSD ($P = 0.05$) values for the respective axes.

from cultivars Hillsdale and Compton that were perceived by the sensory panels. LSD values for the probe resistance data for wire-cut cookies at deformation rates of 20 and 300 mm/min were 35 and 26%, respectively, of the hardness range of the four cultivars, and variances were 29 and 17%, respectively, of the hardness range. The mean square variances of the probe values for the wire-cut formula cookies were significantly ($P = 0.05$) less than those for macromethod cookies.

Postbake Time

Curley and Hoseney (1984) used a three-point break test to show that macromethod sugar-snap cookies develop "snap" as they age for up to three days. They theorized that the increasing snap resulted from sucrose recrystallization.

Our study used probing techniques to measure changes in the hardness of cookies produced from the four cultivars by the three laboratory methods one, two, and three days after baking. The mean probe resistance data over the three days showed trends that were usually not statistically significant (Table IV). Probe resistance of wire-cut cookies decreased after the first day and remained relatively constant on the third day. The probe resistance and statistical error increased with each day of storage for macromethod cookies and decreased with each day of storage for micromethod cookies. Because cookie hardness is dynamic over time, it is best to evaluate hardness at a standardized time after baking.

Probe resistance of both wire-cut formula and micromethod cookies decreased with time. Both formulas have a relatively high shortening-water ratio, which affects mixing efficiency and should allow less protein network development during mixing and baking expansion. The less developed protein network may interfere less with the development of brittleness that may result from sugar recrystallization and/or glass formation, depending on cookie formulation.

The three-point break technique can evaluate both hardness and brittleness. When it was used to evaluate wire-cut formula cookies made from the four cultivars one, two, and three days after baking, peak force and snapping force increased with storage time across cultivars, indicating increased product hardness (Table V). Young's modulus increased and the modulus of deformability decreased with postbake time, indicating increasing brittleness.

As measured by the three-point break technique, both hardness and brittleness of wire-cut formula cookies increased up to three days after baking. The increased brittleness appears to have influenced the compression and/or shear components of the probe technique, lowering the magnitude of resistance to probing.

Thus, it can be useful to have data from both techniques. However, the three-point break technique allows only one break per cookie, and the resulting estimates of variance include method variables (instrument errors and within-cookie variance) as well as cookie-to-cookie variance. With the probing technique, we used the mean of 13 probings per cookie to reduce variance within cookies, allowing estimates of variance to represent mostly cookie-to-cookie variation. However, if brittleness is a major influence on product texture, then the three-point break technique could be more reliable. The calculated snapping force, which estimates breaking force as a function of product geometry, and Young's modulus, which estimates brittleness as a function of force and time, produced slightly better statistical differences among means for days after baking than did the "raw data" for force (peak force) and time (modulus of deformability).

CONCLUSIONS

We used a probing test to evaluate the hardness of cookies produced by three laboratory methods, the AACC micromethod and macromethod for producing sugar-snap cookies and a new formula for wire-cut cookies. The three cookie formulations differed in sugar-shortening-water ratios as well as in quantities of dough produced (and flour required). Probing data for wire-cut formula cookies showed less variance than probing data for macromethod cookies and usually had smaller LSD values compared to the range of hardness evaluated.

TABLE IV
Effect of Postbake Time on Mean Probe Resistance (PR), Standard Deviation (SD), and Coefficient of Variation (CV) for Cookies Produced from Four Soft Wheat Cultivars by Three Formulas

Postbake Time (Days)	AACC Micromethod			AACC Macromethod			Wire-Cut Formula		
	PR[a]	SD	CV	PR[a]	SD	CV	PR[a]	SD	CV
1	21.0 a	1.94	9.23	49.3 a	7.38	15.0	25.6 a	2.68	10.5
2	20.3 ab	1.04	5.14	50.4 a	9.73	19.3	24.5 a	3.16	12.9
3	18.8 b	0.85	4.55	52.5 a	10.50	19.9	24.3 a	2.64	10.9

[a] Means in a column followed by the same letter are not statistically different ($P = 0.05$).

TABLE V
Mean Peak Force, Snapping Force, Young's Modulus, and Modulus of Deformability and Corresponding Standard Deviation (SD) and Coefficient of Variation (CV) for Wire-Cut Formula Cookies Produced from Four Soft Wheat Cultivars and Evaluated One, Two, and Three Days After Baking[a]

Source	Time After Bake (days)		
	1	2	3
Peak force, kg	8.1 a	9.0 ab	9.2 b
SD	0.53	0.81	0.65
CV	6.5	9.0	7.0
Snapping force, kg/cm^2	10.7 a	12.9 b	13.1 b
SD	1.12	0.99	0.64
CV	10.5	7.7	4.9
Young's modulus, kg/min	152 a	173 ab	192 b
SD	14.0	16.8	15.1
CV	9.2	9.7	7.9
Modulus of deformability, sec	3.3 a	3.2 a	3.0 a
SD	0.19	0.10	0.26
CV	5.8	3.3	8.9

[a] Means in a row followed by the same letter are not significantly, different ($P = 0.05$).

For probing studies, we used a large probe size (but not large enough to crack or break the product) and a relatively fast deformation rate and chose a standardized time after baking of two days for measuring hardness. A three-point break technique was used to measure the hardness and brittleness of wire-cut formula cookies as they aged. Cookies became harder and more brittle for up to three days after baking. Compared to the probe technique, the three-point break technique requires more product than may be routinely practical to produce in the laboratory.

This investigation suggests that, except when differences in hardness are small, the combination of the wire-cut formulation for laboratory cookie production with the probing test for hardness measurement has potential for improving the quality and consistency of cookies and for predicting cultivar and flour quality. Application of these techniques is explored in Gaines et al (1992).

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