

Instrumental and Sensory Assessment of Oatmeal and Chocolate Chip Cookies Modified with Sugar and Fat Replacers

J. M. Perry,¹ R. B. Swanson,^{1,2} B. G. Lyon,³ and E. M. Savage³

ABSTRACT

Cereal Chem. 80(1):45–51

Sensory texture and flavor parameters of three formulations of two popular cookies were evaluated by a trained descriptive panel. Probing, a puncture test, was used to assess texture instrumentally. Other physical tests included water activity, cookie spread, and specific gravity. Chocolate chip and oatmeal cookies were prepared using a nonsucrose sweetener blend (dextrose/acesulfame-K) or prune puree, following manufacturers' recommendations, to replace 50% of the sugar or fat, respectively. The three formulations differed in ratios of flour, sugar, fat, and water.

Instrumental and sensory evaluations occurred the day after baking. Data were analyzed using analysis of variance and means separation tests ($P < 0.05$). Relationships between sensory and instrumental assessments were identified with correlations. According to the trained panel, sugar and fat replacement had a greater effect on texture than on flavor. Probing was successfully used to assess textural attributes of cookies. Correlations revealed that the area under the curve was the best predictor of sensory hardness and chewiness, regardless of cookie type.

Ninety percent of adult Americans consume reduced-fat and low-calorie foods, while 29% consume reduced-in-sugar products (CCC 1999). Use of these modified products in conjunction with other fat reduction strategies results in better dietary micronutrient and macronutrient profiles (Petersen et al 1999). Cookies represent a significant share of the modified product market. Effects of product modification on sensory attributes, as well as dietary benefits, must be considered in the development of high-quality, acceptable products (Setser and Racette 1992).

Cookies are high-fat, high-sugar, and low-moisture products. Formulations are typically 30–75% sugar, 30–60% fat, and 7–20% water on a flour weight basis (Pylar 1988). Sucrose reduction and the use of high-intensity sweeteners including acesulfame-K (ace-K) have been investigated. However, a loss of sweetness and presence of a bitter aftertaste in shortbread cookies containing ace-K have been reported (Redlinger and Setser 1987). When coupled with other high-intensity sweeteners in shortbread cookies, ace-K exhibited time intensity sweetness profiles similar to those of sucrose, with relatively low levels of bitterness, although textural attributes were altered (Lim et al 1989). In traditional cookies, sucrose contributes to cookie spread as well as the characteristic fracturability or "snap" (Curley and Hosney 1984; Alexander 1998). Ace-K may also be blended with other nutritive sugars to provide some of the additional bulk and flavor that is usually lost with sucrose reduction (Peck 1994). Commercially, ace-K has been marketed in combination with dextrose (Sweet One, Stadt Corp., Brooklyn, NY).

Fat primarily produces more tender products and shorter doughs. Fat reduction often results in a cookie with a chewy texture, nontraditional snap characteristics, and an intermediate final moisture content (Armbrister and Setser 1994; Sanchez et al 1995; Swanson et al 1999). Acceptable reduced-in-fat (50%) oatmeal and chocolate chip cookies have been formulated with prune puree (Swanson and Munsayac 1999). Prune puree, a fruit-based fat substitute, contains fiber, pectin, sorbitol, and reducing sugars that aid in controlling added water and in providing sweetness and humectancy. These properties minimize the difficulties of fat and sugar reduction in low-moisture products such as cookies.

Cookie flavor has been characterized by sensory panels (Lim et al 1989; Armbrister and Setser 1994), whereas texture has been assessed

with both instrumental and sensory techniques (Gaines et al 1992a,b; Armbrister and Setser 1994; Sanchez et al 1995; Swanson et al 1999). Instrumental methods that accurately assess textural changes and that are validated by sensory methods are needed for bench-top testing and quality control of modified products (Meilgaard et al 1999). Such methods would alleviate some of the time and expense associated with sensory panels.

The three-beam technique has been used to assess textural quality (hardness and fracturability) of the traditional crisp, tender cookie. In this technique, the product is placed on two beams a known distance apart, and a third beam is lowered onto the cookie at a point equidistant from the two supports. The deformation (bend) and force at break (snap) are measured. An instrumental probing method, recently suggested as an alternative to the three-beam technique (Gaines et al 1992a; Gaines 1994), could prove to be more practical and reliable. In this method, the force required to push a probe into or through the product is measured at multiple locations in a single cookie. When used to assess three experimental cookie formulations that differed in sugar-to-shortening-to-water ratios, the test required less product and provided better estimates of within-cookie variation when compared to the three-beam technique (Gaines et al 1992a). Maximum peak force reportedly indicates cookie hardness (Gaines et al 1992ab). However, possible relationships between other probe parameters and sensory texture attributes have not been explored.

The objectives of this study were to 1) profile sensory flavor and texture attributes of three formulations (full-fat control, reduced-in-fat, reduced-in-fat and sugar) from two popular cookie types (chocolate chip and oatmeal) with a trained sensory panel; 2) assess texture using physical techniques including probing; and 3) determine relationships between probing parameters and sensory assessments of texture.

MATERIALS AND METHODS

Materials

Oatmeal and chocolate chip cookies were prepared in three formulations: full-fat control (FFC), reduced-in-fat (RF), and reduced-in-fat and sugar (RFS) (Table I). RF and RFS cookies contained prune puree (Sunsweet Growers, Yuba City, CA). RFS cookies also were formulated with an alternative sweetener containing acesulfame-K and dextrose (Sweet One). Sugar and fat substitutions were made according to manufacturer's directions (Sweet One package insert; CPB 1999).

Preparation Methods

All ingredients except eggs and butter were purchased at the beginning of the study and were from the same lot. Eggs and butter were purchased from the same lot weekly. Before mixing, eggs and butter were held at room temperature for 45 min.

¹ Dept. of Foods and Nutrition, University of Georgia, Athens, GA 30602.

² Corresponding author. E-mail: rswanson@fcs.uga.edu. Phone: 706-542-4834. Fax: 706-542-5059.

³ USDA-ARS, Russell Research Center, Athens, GA 30605.

All cookies were mixed in a Kitchen Aid mixer (model K5SS, St. Joseph, MI) and baked in a rotary oven (National Mfg. Co., Lincoln, NE). Oatmeal cookies were prepared by blending all dry ingredients (Table I), including alternative sweeteners when appropriate, for 1 min at speed 1. Shortening, butter, eggs, vanilla, and prune puree, when appropriate, were incorporated at speed 2 for 2 min. Chocolate chip cookies were prepared by creaming butter, sugar, brown sugar, vanilla, and alternative sweeteners and prune puree, when appropriate, at speed 1 for 1 min. Beaten eggs were incorporated at speed 2 for 2 min. Previously blended flour, salt, and baking soda mixture was incorporated over a 2-min period at speed 2. Chocolate chips were incorporated at speed 1 for 1 min. Doughs were gently scooped with a No. 60 scoop (17 ± 2 g), and deposited in six rows down and three across on a half-sheet pan (41.9×30.5 cm). Cookies were flattened with a single back and forth stroke of a rolling pin (Approved Method 10-50D, AACC 2000); dough guides (0.6 cm) were used. Oatmeal cookies were baked at 176°C for 11 min; chocolate chip cookies were baked at 190°C for 10 min. After cooling for 1 hr, cookies were stored in sandwich bags 1.2 mL thick (Ziplock, SC Johnson and Son, Racine, WI) under ambient conditions until evaluated.

Physical and Physicochemical Measurements

Specific gravity (Penfield and Campbell 1990) was determined on three dough samples from each treatment. Cookie spread (Approved Method 10-50D) was determined in duplicate for each treatment. Both tests were conducted on the day of baking. Water activity was determined 18–20 hr postbake on six aliquots/treatment with the Aqua Lab device (Decagon Devices, Pullman, WA). Aliquots were taken from composite samples prepared from six crumbled cookies/treatment (Cuisinart, mini-prep food processor) as described by Curley and Hoseney (1984).

Four cookies/treatment/replicate were probed (Bourne 1975, 1999; Gaines et al 1992a,b) at 14–18 hr postbake. A 50-kg capacity texture analyzer (TA.XT2, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, England), equipped with Texture Expert software (v. 1.20, Stable Micro Systems) was used. Cookies were placed on an aluminum plate 1.3 cm thick with a hole 0.6 cm in diameter that accepted the 0.3-cm probe as it punched through the product at a travel distance of 25 mm. Trigger force was 10 g and the cross-arm speed was 5 mm/sec.

Each probe provided a force-time curve with one peak from which the following parameters were obtained: slope, peak force, time to peak force, and area under the curve. Sample height also was determined at point of contact by the probe. Each cookie was probed in nine locations forming an “X” pattern (Fig. 1). To avoid

edge effects, the outer 15% of the cookie was not probed. For statistical analysis, data from the center point (probe 1), the average inner concentric circle value (probes 6–9), and the average outer concentric circle value (probes 2–5) were used.

Trained Sensory Panel

Cookies were evaluated by an eight-member trained sensory descriptive panel (Spectrum Method) (Meilgaard et al 1999) from the USDA-ARS Sensory Laboratory, Russell Research Center, Athens, GA. Panelists participated in additional training sessions to identify cookie product attributes, clarify reference terminology, and verify or establish references as anchor points for flavor and texture attribute intensity levels (Table II). Panelists’ discriminating ability, consistency, and reliability were verified on training samples before testing through panel discussions and various statistical measures including means, standard deviations, and ANOVA (Powers 1984).

Computerized 15-point line scales were utilized for product evaluations (CompusenseFive, v. 4.3, Guelph, ON, Canada). Warm-up samples were provided for panelist self-calibration. Sensory test samples were randomly selected from the same batch used for physical and physicochemical testing. Panelists were presented with three cookie samples one at a time (one from each cookie formulation within cookie type) under low-pressure sodium-vapor lighting (CML-18, Trimble House, Norcross, GA). Samples were coded with three-digit random numbers and order of presentation was balanced (Meilgaard et al 1999). Filtered water, apple slices, and unsalted crackers were provided for palate cleansing between samples.

Experimental Design and Statistical Analyses

A randomized, complete block factorial design was used. Cookie type, either oatmeal or chocolate chip, was blocked over the complete design. The study was replicated three times. Eight trained sensory panelists evaluated three treatments (FFC, RF, RFS) from the same cookie type during a single panel session. These treatment combinations also were used for physical and physicochemical tests.

All data were analyzed using a statistical package (SAS for Windows, v. 6.12, SAS Institute, Cary, NC). Equal variance within treatment from the instrumental and sensory analyses was verified (PROC MEANS). Normality plots (PROC UNIVARIATE) were used to verify normal distribution and equal variance of the data. Data were analyzed for variance ($P < 0.05$) due to main effects and interactions with PROC GLM. Least-square mean values (LS-means) were generated and PDIFF was used for LS-means separation when appropriate (DiIoria 1991). Relationships between sensory and instrumental parameters were analyzed using the Pearson’s Product Moment correlation statistic ($P < 0.05$).

TABLE I
Oatmeal and Chocolate Chip Cookie Formulas (fwb)

Ingredient	Cookie		Source
	Oatmeal	Chocolate Chip	
All-purpose flour	100.0	100.0	Southeastern Mills, Rome, GA
Baking soda	1.3	1.0	Gilster-MaryLee, Chester, IL
Iodized salt	1.3	1.8	Frosty Acres, Norcross, GA
Old-fashioned oats	71.9	...	Quaker Oats, Chicago, IL
Ground cinnamon	0.5	...	McCormick & Co., Hunt Valley, MD
Ground nutmeg	0.3	...	Kroger Cincinnati, OH
Ground cloves	0.1	...	Kroger, Cincinnati, OH
Granulated sugar ^a	45.0	48.6	PYA Monarch Regency, Greenville, SC
Light brown sugar	74.0	35.4	Dixie Crystals, Savannah, GA
Imitation vanilla flavoring	1.0	1.3	Greinaman’s/Unified Industries, Cumming, GA
Egg	38.0	36.9	Kroger, Cincinnati, OH
Salted butter ^b	47.0	73.7	Land O’Lakes, Garden Hills, MN
Shortening ^b	56.0	...	Archer Daniels Midland, Valdosta, GA
Mini semi-sweet chocolate chips	...	89.2	Hershey’s Food Corp., Hershey, PA

^a In reduced fat and sugar (RFS) formulation, granulated sugar was reduced by 50%; 1.3% (fwb) Sweet One (Stadt Corp., Brooklyn, NY) was incorporated.

^b In reduced fat (RF) and reduced fat and sugar (RFS) formulations, added fat was reduced by 50%; prune puree (Sunsweet Growers, Yuba City, CA) equal to 25% of the total added fat was incorporated.

RESULTS AND DISCUSSION

Cookie Formulations

Use of manufacturer recommendations for fat and sugar reduction (Sweet One package insert; CPB 1999) resulted in differences from the control in the flour-to-fat-to-sugar ratio. Because prune puree, which was used as a fat replacer, contains moisture, water levels were also altered. These differences produced cookies with a range of sensory attributes.

Sensory Flavor Attributes

Sensory flavor profiles for the cookies by type and treatment are shown in Fig. 2. The diagrams represent attribute LS-mean scores of each treatment plotted on truncated line scales radiating from a center point. Attributes (Table II) are arranged in order of evaluation beginning at the 12 o'clock position. Generally, flavor attributes of the modified cookies (RF and RFS) were similar to the control (FFC) for each cookie type.

No significant difference in sweetness intensity for either cookie type was found, regardless of product modification. Slight decreases in sweetness intensity have been reported when ace-K alone replaced 100% of the sugar in shortbread cookies (Redlinger and Setser 1987). Sweetness intensity also decreased in chocolate chip cookies when carbohydrate-based fat replacers, including citrus peel pectin, replaced either 50 or 75% of the shortening (Armbrister and Setser 1994). Pectin is a major functional component of prune puree (CPB 1999).

In oatmeal cookies, prune and butter flavor intensity reflected product formulations. Prune flavor was not detected in the chocolate chip cookie, although a decrease in butter intensity was found in the modified treatments, reflecting product formulations (Table I). RFS oatmeal cookies had a significantly stronger brown sugar note than the FFC, whereas the RF cookie did not differ significantly from either of the other formulations. In chocolate chip cookies, intensities of both brown sugar and chocolate flavor notes were significantly greater in the modified cookies than in the FFC, although the modified cookies did not differ significantly from each other. These trends suggest a possible effect of fat reduction or prune puree incorporation. Prune puree contains malic acid, fructose, and sorbitol, which carry and enhance other flavors in the system (Alexander 1998; CPB 1999; Nelson 2000). Ace-K in combination with sorbitol also results in improved initial sweetness and rounds out the flavor (Bullock et al 1992). No significant differences in the remaining flavor attributes were found for either cookie type.

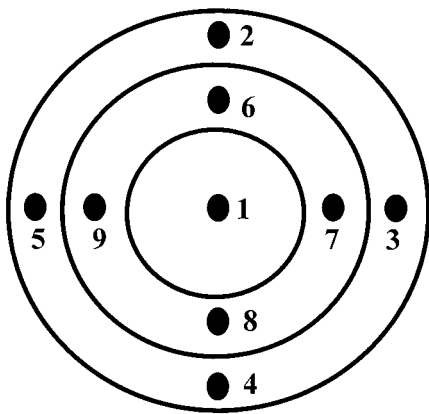


Fig. 1. Representative X pattern for probing chocolate chip and oatmeal cookies. Each point represents one probe obtained with a 50-kg capacity texture analyzer using a 0.3-cm probe at a cross-arm speed of 5mm/sec. Nine probes were obtained from each cookie, avoiding the outer edge (15%). Data from the center point (probe 1), inner concentric circle (average of probes 2–5) and outer concentric circle (average of probes 6–9) were used for analysis (Table IV).

Sensory Textural Attributes

Sensory results for textural attributes are shown in Fig. 3. Significant differences due to sugar or fat replacement were found. Generally, modified cookies were more similar to each other than either was to the FFC. However, sugar replacement with dextrose/ace-K sweetener (Sweet One) blend in combination with fat replacement with prune puree tended to moderate the effects of fat replacement alone.

Panelists' assessment of hardness, both manually and orally, followed similar trends within cookie type. Both RF cookies were harder than the FFC. Conversely, Armbrister and Setser (1994) reported trained sensory panelists perceived reduced-fat chocolate chip cookies to be less firm than the full-fat controls when various carbohydrate-based fat replacers were incorporated. However, prune puree was not evaluated. Swanson and Munsayac (1999) reported that consumer panelists rated both RF oatmeal and chocolate chip cookies made with prune puree softer than the full-fat versions.

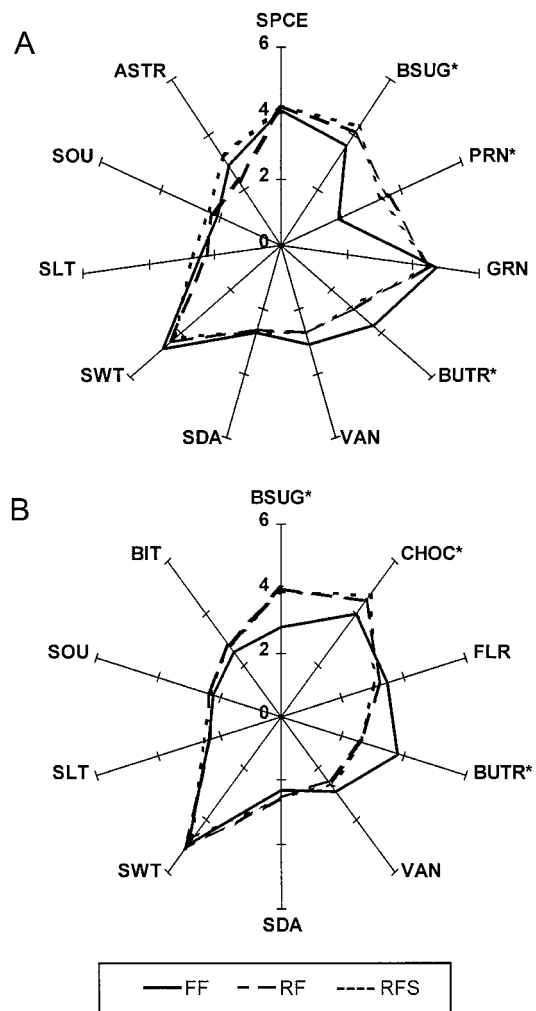


Fig. 2. Descriptive profiles of flavor attributes of oatmeal (A) and chocolate chip (B) cookies prepared in three formulations: full-fat control (FFC), reduced-in-fat (RF), reduced-in-fat and sugar (RFS). Attribute LS-means for each formulation are plotted on truncated line scales radiating from the center, clockwise in the order of evaluation beginning at the 12 o'clock position. Significant differences ($P < 0.05$) among formulations for an attribute are indicated with *. Flavor attributes and abbreviations are brown sugar/caramelized (BSUG) in chocolate chip cookies, chocolate (CHOC), white wheat flour (FLR), cinnamon/woody spice (SPCE), brown sugar/molasses (BSUG) in oatmeal cookies, prune puree (PRN), grainy/oatmeal (GRN), buttery (BUTR), vanilla (VAN), soda (SDA), sweet (SWT), salty (SLT), sour (SOU), astringent (ASTR).

TABLE II
Flavor and Texture Attributes, Definitions, and References Used by Trained Sensory Panel to Evaluate Oatmeal and Chocolate Chip Cookies^a

Attribute	Abbreviation	Definition by cookie type		References/anchors	
		Oatmeal	Chocolate Chip	0 none	15 much
----- Flavor Attributes -----					
Phase I- Aromatic Flavor Notes				The following universal reference scale was applied to aromatic flavor notes: 2--soda note in saltine crackers 5--grape note in grape Kool-aid 7--orange note in orange juice from concentrate 9.5--orange note in Tang 10--grape note in Welch's grape juice 12--cinnamon note in Big Red gum	
Brown sugar/caramelized	BSUG		Aromatic associated with brown sugar/caramelization		
Chocolate	CHOC		Aromatic associated with chocolate.		
White wheat flour	FLR		Aromatic associated with white wheat flour.		
Cinnamon/woody spice	SPCE	Aromatic associated with cinnamon and non-specific spices.			
Brown sugar/molasses	BSUG	Aromatic associated with brown sugar/molasses.			
Prune puree	PRN	Aromatic associated with prune puree.			
Grainy/oatmeal	GRN	Aromatic associated with non-specific grain/oatmeal.			
Butter	BUTR	Aromatic associated with butter.			
Vanilla	VAN	Aromatic associated with vanilla.			
Soda	SDA	Aromatic associated with soda.			
Phase II- Basic Tastes					
Sweet	SWT	Basic taste on the tongue stimulated by sugars and high potency sweeteners.		Sucrose, solution in water 2.0% (2)-----5.0% (5)-----10.0% (10)-----15.0% (15)	
Salty	SLT	Basic taste on tongue stimulated by sodium salt, especially sodium chloride.		NaCl, solution in water 0.2% (2.5)-----0.35% (5)-----0.5% (8.5)-----0.7% (15)	
Sour	SOU	Basic taste on tongue stimulated by acids.		Citric acid, solution in water 0.05% (2)-----0.08% (5)-----0.15% (10)-----0.20% (15)	
Bitter	BIT	Basic taste on tongue stimulated by solutions of caffeine, quinine, and certain other alkaloids.		Caffeine, solution in water 0.05% (2)-----0.08% (5)-----0.15% (10)-----0.20% (15)	
Phase III- Aftertaste Feeling Factor					
Astringency (Oatmeal only)	ASTR	Chemical feeling factor in the mouth described as puckering/dry.		Tea bags /1 h soak -----(6.5)	
----- Mouthfeel/texture -----					
Phase I- Evaluated by breaking with fingers					
Manual hardness	MHRD	Manual force required to break or separate the sample into two pieces.		Pringle (4)-----Ginger snap (10)	
Manual fracturability	MFRC	The manual force with which the sample breaks.		Graham cracker (4)---Ginger snap (8)----Peanut Brittle (13)	
Phase II- Evaluated surface characteristic with lips					
Roughness	RGH	Amount of particles in the surface as detected by the lips.		Gelatin dessert (0)-----Pringles (8)-----Rye wafer (15)	
Phase III- Evaluated with front teeth					
Oral fracturability	OFRC	The force with which the sample breaks at first bite with front teeth.		Graham cracker (4)---Ginger snap (8)----Peanut Brittle (13)	
Phase IV- Evaluated after first bite with molars					
Cohesiveness	COH	Degree to which the sample deforms rather than ruptures/breaks after 1 bite using the molars.		Corn bread (1)-----Raisin (10)-----Chewing gum (15)	
Oral hardness	OHRD	Force required to bite through the sample after 1 bite with the molars.		American cheese (4)----Peanuts (9.5)----Lifesavers (14.5)	
Phase V- Evaluated during chewdown					
Oily	OIL	Amount of oil in sample.		Saltine (0)-----Tuna in oil (11)	
Chewiness	CHW	Amount of work to chew sample to point of swallow.		Rye bread (1.5)---Gum drop (8.5)-----Tootsie roll (13)	
Phase VI- Evaluated after swallow					
Residual particles	RESD	Amount of particles left in the mouth		Nabisco oatmeal cookie (~5)	
Oily mouthcoat	OMCT	Amount of oily coating left in the mouth		Keebler Chips Deluxe Soft and Chewy cookie (~5)	

^a Sensory profile attributes were determined by the in-house panel (USDA-ARS, Athens, GA). Definitions and references for flavor terms, basis tastes, and astringency were obtained from Civille and Lyon (1996), modified as appropriate. Texture definitions and references were from Meilgaard et al (1999), modified as appropriate. Manual hardness and manual fracturability were defined by the in-house panel.

Generally, sugar reduction and replacement in combination with fat reduction and replacement tended to mitigate the effects of fat replacement alone. The RFS and FFC chocolate chip cookies were not significantly different in hardness, whether assessed manually or orally. Although the RFS oatmeal cookies did not differ significantly from the RF cookie, there was a trend toward decreased hardness when both sugar and fat levels were altered. Sucrose reduction likely contributed to less recrystallization. As sucrose recrystallizes, the cookie loses flexibility, and the texture becomes hard and crisp (Curley and Hosenev 1984). Increases in hygroscopic components, including sorbitol and fructose (Alexander 1998), likely contributed to a softer cookie.

The FFC oatmeal cookies exhibited significantly higher fracturability than the modified cookies, which did not differ from each other. The chocolate chip cookie formulations, all of which were relatively soft, did not differ significantly in manual fracturability. When assessed orally, sugar reduction moderated the decrease in fracturability found with fat reduction and replacement alone. Previously, Armbrister and Setser (1994) reported that chocolate chip cookies made with fat replacers were significantly less fracturable than the FFC. Lim et al (1989) reported that shortbread cookies made with sucrose were more fracturable than were those made with high intensity sweetener blends.

Both oatmeal and chocolate chip RF cookies exhibited significantly higher cohesiveness and chewiness than the FFC. Typically, a product that is cohesive requires more work to chew to the point of swallow (Fig. 3). These effects in RF cookies are attributed to fat reduction, increased moisture content, and increased gluten development, and support previously reported effects on cohesiveness (Armbrister and Setser 1994). Reducing and replacing 50% of both fat and sugar with prune puree and the nonsucrose sweetener blend, respectively, tended to moderate this effect.

Modified cookies did not differ from the FFC in surface roughness, regardless of cookie type. In the chocolate chip cookies, the modified cookies differed from each other but not from the FFC, which had intermediate surface roughness. Previously, decreases in surface roughness observed in RF chocolate chip cookies have been attributed

to shortening reduction and the associated increase in water content (Armbrister and Setser 1994).

For both cookie types, there were no significant differences among the three treatments in oily, oily mouthcoat, or residual particles. Armbrister and Setser (1994) previously reported that RF chocolate chip cookies had a significantly higher level of residual particles when compared with the control cookie.

Physical and Physicochemical Tests

Physical and physicochemical measurements are reported by cookie type and treatment in Table III. These tests revealed similar modification effects for both cookie types.

Specific gravity increased with both sugar and fat replacement, indicating decreased dough aeration (Kamel 1994; Alexander 1998). Armbrister and Setser (1994) also found that 50 or 75% fat replacement in chocolate chip cookies with various fat replacers resulted in increased specific gravity when compared with the FFC.

Water activity increased with modification. Both RF cookies were intermediate in a_w . Increased a_w due to fat replacement in cookies was previously reported (Swanson et al 1999). RFS had the highest a_w values. Typically, nutritive sweeteners bind water in the food system, lowering the a_w (Alexander 1998).

Cookie spread decreased with sugar and fat reduction. FFC cookies were thin with a wide diameter. Fat replacement resulted in thicker cookies with reduced diameters. Cookies reduced in both fat and sugar exhibited the least amount of spread (Table III). These results are consistent with the probe data for product height. As sucrose levels are decreased, dough fluidity associated with melting of sucrose during baking is reduced. Sugars also delay starch gelatinization (Spies and Hosenev 1982) and increase the gluten glass transition temperature (Doescher et al 1987a). Lower gluten glass transition temperatures due to sugar reduction are associated with less spread (Doescher et al 1987a). Spread is also limited at lower sugar levels as more water is bound by the flour, allowing increased gluten development (Doescher et al 1987b).

The probing parameters of time to maximum force and slope suggest that the FFC cookies of both types were less chewy than

TABLE III
Least-Square Mean Values (LS-means) and Standard Error of Physicochemical Tests
for Oatmeal and Chocolate Chip Cookies^a

Cookie Type	Physicochemical Test	Control	Reduced Fat ^b	Reduced Fat and Sugar ^{b,c}	Standard Error
Oatmeal	Specific gravity ^d	1.04a	1.09b	1.07b	0.01
	Water activity ^e	0.32a	0.39b	0.41c	0.00
	Cookie spread ^f	114.60a	84.70b	75.00c	0.70
	Probe ^g				
	Product height (mm)	8.90a	10.30b	11.30c	0.10
	Force (g)	1,450.40ab	1,604.10a	1,299.30b	63.20
	Time (sec)	0.40a	0.52ab	0.62b	0.05
Chocolate Chip	Slope (g/sec)	4,551.80a	4,073.50ab	3,139.90b	398.80
	Area	921.60a	1,677.10b	1,459.50c	66.80
	Specific gravity ^d	1.04a	1.12b	1.11b	0.00
	Water activity ^e	0.33a	0.38b	0.42c	0.00
	Cookie spread ^f	120.80a	85.00b	77.60c	1.30
	Probe ^g				
	Product height (mm)	10.00a	11.00b	12.20c	0.20
	Force (g)	1,267.90a	1,284.70a	918.60b	55.80
	Time (sec)	0.30a	0.50b	0.46b	0.03
	Slope (g/sec)	5,025.50a	3,121.40b	2,629.30b	325.70
Area	628.50a	1,138.10b	778.00c	39.90	

^a LS-means within cookie type and parameter followed by different letters were significantly different according to ANOVA and LS-means separation with the PDIFF option ($P < 0.05$) (DiIoria 1991).

^b 50% of the added fat was replaced with prune puree (Sunsweet Growers, Yuba City, CA). Substitutions for modified formulations were equal to 25% of the added fat in the control formulation.

^c Sweet One (Stadt Corp., Brooklyn, NY) substitutions were 4.5 g of Sweet One replacing 75 g of granulated sugar in chocolate chip cookies; 3 g of Sweet One replacing 50 g of granulated sugar in oatmeal cookies.

^d LS-means are across three replicates on three samples/replicate (Penfield and Campbell 1990).

^e LS-means are across three replicates with six analyses/replicate measured using Aqua Lab (Decagon Devices, Pulman, WA).

^f LS-means are across two determinations and three replicates (Approved Method 10-50D, AACC 2000).

^g LS-means based on three values/cookie (center probe, averaged inner concentric circle, and averaged outer concentric circle) with four cookies/three replicates determined with a 50-kg capacity texture analyzer and a 0.3-cm probe at a cross-arm speed of 5 mm/sec (Bourne 1975, 1999; Gaines et al 1992a).

TABLE IV
Pearson's Product Moment Correlation Coefficients^a Between Sensory Attributes^b
and Probe Parameters^c for Oatmeal and Chocolate Chip Cookies

Sensory Parameters	Probe Parameters for Oatmeal Cookies					Probe Parameters for Chocolate Chip Cookies				
	Product Height (mm)	Force (g)	Time (sec)	Slope (g/sec)	Area	Product Height (mm)	Force (g)	Time (sec)	Slope (g/sec)	Area
Manual hardness (MHRD)	<i>r</i>		0.60		0.77					0.90
	<i>P</i>		0.09		0.02					<0.01
Oral hardness (OHRD)	<i>r</i>	0.66			0.88					0.92
	<i>P</i>	0.05			<0.01					<0.01
Manual fracturability (MFRC)	<i>r</i>	-0.86			-0.72			-0.67		
	<i>P</i>	<0.01			0.03			0.05		
Oral fracturability (OFRC)	<i>r</i>	-0.80	-0.61		-0.77			-0.67	0.62	
	<i>P</i>	0.01	0.08		0.01			0.05	0.07	
Cohesiveness (COH)	<i>r</i>				0.85			0.76		0.71
	<i>P</i>				0.01			0.02		0.03
Chewiness (CHW)	<i>r</i>	0.64			0.83			0.61		0.83
	<i>P</i>	0.06			0.01			0.08		0.01
Roughness (RGH)	<i>r</i>			-0.66			0.68			0.66
	<i>P</i>			0.05			0.04			0.05
Oiliness (OIL)	<i>r</i>		0.58					0.63		
	<i>P</i>		0.10					0.07		
Oily mouthcoat (OMCT)	<i>r</i>			0.69				0.63		
	<i>P</i>			0.04				0.07		
Residual particles (RESID)	<i>r</i>	0.78	-0.64							
	<i>P</i>	0.01	0.06							

^a Only values for correlation coefficients $r > 0.55$ are given with their corresponding probability value (P).

^b Correlation values across eight panelists by three replicates within each cookie type. Sensory scales ranged from 0 = low intensity to 15 = high intensity.

^c Samples ($n = 36$) measured using a 50-kg capacity texture analyzer and a 0.3-cm probe at a cross-arm speed of 5 mm/sec (Bourne 1975, 1999; Gaines et al 1992a).

the RFS cookies. Cookie type influenced the effect of fat reduction on chewiness. Chewy products exhibited persistent resistance to penetration, increasing the time to penetration. These results and those from sensory analysis followed the same general trends, although some differences were noted.

Previously, force measured as the probe penetrates through the cookie was reported as hardness (Gaines et al 1992a,b; Gaines 1994). For cookies in this study, both fat and sugar reduction resulted in a maximum penetration force that was either similar to or lower than the FFC. In cookies in which only fat was reduced, penetration force was not different from the FFC. Conversely, sensory panelists indicated RF cookies from both types were harder than the FFC. Area under the curve integrates both maximum force to penetrate and the force measured over time or distance. Sanchez et al (1995) suggested that area under the force-time curve represented toughness, which increased with fat replacement in shortbread cookies. Jowitt (1974) defined sensory toughness as a high and persistent resistance to breakdown on mastication. RF cookies of both types exhibited the largest areas under the curve. Sugar reduction in addition to fat replacement slightly moderated this effect. Sensory panelists in this study did not specifically evaluate toughness as defined by Jowitt (1974).

Correlations Between Results of Probing and Trained Sensory Panelists

Correlation analysis (Table IV) was conducted to determine whether sensory and instrumental measures of texture were linearly related. Correlation coefficients greater than $r = 0.8$ are typically considered indicative of moderate confidence in the instrumental assessment (Gaines 1994). Generally, these results ($r < 0.8$) show a

lack of a relationship between sensory hardness and probing force or slope for both cookie types. Similarly, sensory assessment of fracturability was not significantly correlated with penetration force or slope. It has been suggested that in some cases, probing force rather than slope of the curve indicates fracturability, while slope indicates hardness (Gaines 1994).

In this study, area under the curve was the best overall indicator of cookie texture for both cookie types, showing a significant correlation with five or six sensory texture attributes. Area is determined by the maximum force required for penetration and the extent to which the cookie bends and deforms before reaching maximum force. In chocolate chip cookies, area predicted 81–85% of the variation in hardness. In oatmeal cookies, 60–77% of the hardness variation was explained. Area under the curve appears to be a better predictor of oral rather than manual hardness.

Area also explained 69% of the variability in sensory chewiness and 50–72% of the variation in sensory cohesiveness in both cookies in this study.

CONCLUSIONS

Trained sensory panelists found differences in both flavor and texture attributes, as expected. Sugar and fat replacement had a greater impact on texture than flavor. Generally, sugar reduction and replacement in combination with fat reduction and replacement tended to mitigate the effects of fat replacement alone. For cookies in this study, area under the probing curve appears to be the best instrumental indicator of sensory assessment of cookie texture. Thus, the need for texture evaluation with a trained sensory panel during continued product optimization may be reduced.

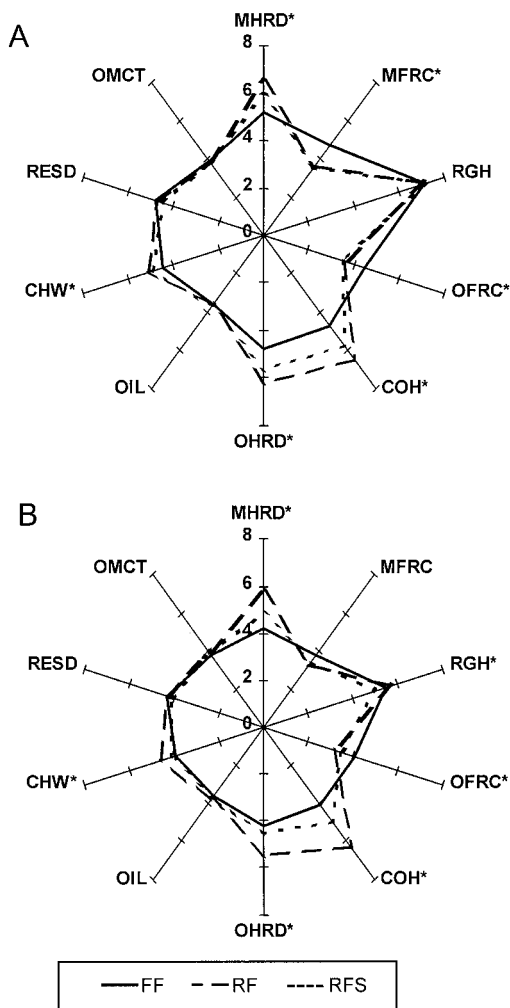


Fig. 3. Descriptive profiles of texture attributes of oatmeal (A) and chocolate chip (B) cookies prepared in three formulations: full-fat control (FF), reduced-in-fat (RF), reduced-in-fat and sugar (RFS). Attribute LS-means for each formulation are plotted on truncated line scales radiating from the center, clockwise in the order of evaluation beginning at the 12 o'clock position. Significant differences ($P < 0.05$) among formulations for an attribute are indicated with *. Texture attributes are manual hardness (MHRD), manual fracturability (MFRC), roughness (RGH), oral fracturability (OFRC), cohesiveness (COH), oral hardness (OHRD), oily (OIL), chewiness (CHW), residual particles (RESD), and oily mouthcoat (OMCT).

LITERATURE CITED

American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. Method 10-50D. The Association: St. Paul, MN.
 Alexander, R. 1998. Nutritive Sweeteners. Eagan Press: St. Paul, MN.
 Armbrister, W. L., and Setser, C. S. 1994. Sensory and physical properties of chocolate chip cookies made with vegetable shortening or fat replacers at 50% or 75% levels. *Cereal Chem.* 71:344-351.
 Bourne, M. C. 1975. Method for obtaining compression and shear coefficients of foods using cylindrical punches. *J. Text. Stud.* 5:459-469.

Bourne, M. C. 1999. Perils and pitfalls of the puncture principle. www.texture-technologies.com. Stable Micro Systems: Godalming, Surrey, England.
 Bullock, L. M., Handel, A. P., Segall, S., and Wasserman, P. A. 1992. Replacement of simple sugars in cookie dough. *Food Technol.* 46(1):82-86.
 CCC. 1999. Light foods and beverages soar to new levels of popularity. www.caloriecontrol.org. Calorie Control Council: Atlanta, GA.
 Civille, G. V., and Lyon, B. G. 1996. Aroma and flavor lexicon for sensory evaluation: Terms, definitions, references and examples. ASTM data series publication DS66. ASTM: West Conshohocken, PA.
 CPB. 1999. The do's and don't's for making reduced fat baked goods using dried plums. www.prunes.org. California Prune Board: Pleasanton, CA.
 Curley, L., and Hosney, R. C. 1984. Effects of corn sweeteners on cookie quality. *Cereal Chem.* 61:274-278.
 DiIoria, F. 1991. SAS Applications and Programming: A Gentle Introduction. Duxbury Press: Belmont, CA.
 Doescher, L. C., Hosney, R. C., and Milliken, G. A. 1987a. A mechanism for cookie dough setting. *Cereal Chem.* 64:158-163.
 Doescher, L. C., Hosney, R. C., Milliken, G. A., and Rubenthaler, G. L. 1987b. Effect of sugars and flours on cookie spread evaluated by time-lapse photography. *Cereal Chem.* 64:163-167.
 Gaines, C. 1994. Objective assessment of cookie and cracker texture. Pages 455-495 in: *The Science of Cookie and Cracker Production*. Hamed Faridi, ed. Chapman and Hall: New York.
 Gaines, C., Kassuba, A., and Finney, P. L. 1992a. Instrumental assessment of cookie hardness. I. Methods assessments. *Cereal Chem.* 69:115-119.
 Gaines, C., Kassuba, A., Finney, P. L. and Donelson, J. R. 1992b. Instrumental measurement of cookie hardness. II. Application to product quality variables. *Cereal Chem.* 69:120-125.
 Jowitt, R. 1974. The terminology of food texture. *J. Text. Stud.* 5:351-358.
 Kamel, B. 1994. Creaming, emulsions, and emulsifiers. Pages 253-282 in: *The Science of Cookie and Cracker Production*. Hamed Faridi, ed. Chapman and Hall: New York.
 Lim, H., Setser, C., and Kim, S. 1989. Sensory studies of high potency multiple sweetener systems for shortbread cookies with and without polydextrose. *J. Food Sci.* 54:625-628.
 Meilgaard, M., Civille, G. V., and Carr, B. T. 1999. *Sensory Evaluation Techniques*, 3rd ed. CRC Press: Boca Raton, FL.
 Nelson, C. 2000. *Alternative Sweeteners*. Eagan Press: St. Paul, MN.
 Peck, A. 1994. Use of Acesulfame K in light and sugar-free baked goods. *Cereal Foods World* 39:743-745.
 Penfield, M. P., and Campbell, A. M. 1990. *Experimental Food Sciences*, 3rd ed. Academic Press: San Diego, CA.
 Petersen, S., Sigman-Grant, M., Eissenstat, B., and Kris-Etherton, P. 1999. Impact of adopting lower-fat food choices on energy and nutrient intake of US adults. *J. Am Diet Assoc.* 99:177-183.
 Powers, J. J. 1984. Using general statistics programs to evaluate sensory data. *Food Technol.* 38(6):74-84.
 Pylar, E. J. 1988. *Baking: Science and Technology*, Vols. 1 and 2. Sosland Publishing Co.: Meriam, KS.
 Redlinger, P. A., and Setser, C. S. 1987. Sensory properties of selected sweeteners: Unbaked and baked flour doughs. *J. Food Sci.* 52:1391-1413.
 Sanchez, C., Klopfenstein, C. F., and Walker, C. E. 1995. Use of carbohydrate-based fat substitutes and emulsifying agents in reduced-fat shortbread cookies. *Cereal Chem.* 72:25-29.
 Setser, C. S., and Racette, W. L. 1992. Macromolecule replacer in food products. *Crit. Rev. Food Sci. Nutr.* 32:275-297.
 Spies, R. D., and Hosney, R. C. 1982. Effect of sugars on starch gelatinization. *Cereal Chem.* 59:128-131.
 Swanson, R., and Munsayac, L. 1999. Acceptability of fruit purees in peanut butter, oatmeal, and chocolate chip reduced-fat cookies. *J. Am. Diet. Assoc.* 99:343-345.
 Swanson, R. B., Carden, L. A., and Parks, S. S. 1999. Effect of a carbohydrate-based fat substitute and emulsifying agents on reduced-fat peanut butter cookies. *J. Food Qual.* 22:19-29.

[Received November 5, 2001. Accepted June 20, 2002.]