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Flour Protein Content and Fat and Sugar Replacers: Effects on Wire-Cut Cookie Spread and Texture and Sensory Perception of Cookie Attributes

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Abstract

For part 1 of a 2-part study, a randomized balanced incomplete design, blocked on day, was used to test the effects of 4 flours at 5.8, 7.5, 8.8, and 10.4% protein, 3 fat replacers (Betatrim, Stardri, and Simplesse) at 0, 35, 55, 75% fat reduction, and 3 sugar replacers (Sucralose, Isomalt, and Maltitol) at 0, 45, and 65% sugar reduction on cookie quality. Cookie spread (width/thickness) and hardness (g) were measured.

Full-fat and 35 and 55% reduced-fat cookie spread decreased as flour protein increased ($p = 0.0102$) as did flour hydration properties. Within each flour, cookies made with Betatrim at 55 and 75% were smaller than full-fat cookies; at similar fat levels, Stardri produced cookies larger than full-fat cookies. For all fat replacers, 75% reduced-fat cookies with 5.8% protein flour were larger than their respective 35% reduced-fat/10.4% protein flour cookies. Full-fat and 35% reduced-fat cookies were softer as flour protein increased from 7.5 to 10.4% ($p = 0.0053$). For each flour, Stardri fat replacement produced harder cookies than all reduced-fat cookies.

For Part 2, a randomized incomplete design, blocked on day and panelist, was used to test 30 optimal wire-cut cookie formulas selected from Part 1. A trained panel (n=12) rated cookies made with the low-protein flour/full-fat and low-protein flour/Simplesse darker than all other treatments ($p = 0.0045$); Isomalt with any fat/fat replacer system produced cookies similar in baked color to control cookies ($p = 0.0075$). Full-fat/low-protein flour ($p = 0.0007$) and full-fat/full-sugar ($p = 0.0025$) were the driest cookies. Full-fat/full-sugar cookies and Stardri cookies with any sugar/sugar replacer system were harder than all other treatments ($p = 0.0251$). Cookies made with the low-protein flour had larger crumb cell size ($p < 0.0001$), were more brittle (p =

0.0005), had more intense browned flavor ($p = 0.0150$), and were sweeter ($p = 0.0003$) than cookies made with the higher protein flours.

Bakers must recognize that low-protein flours can be used to optimize reduced-fat cookie spread, texture, appearance, and flavor. Isomalt and Maltitol are also two sugar replacers that formulators can use in reduced-fat cookies that will produce cookie textures similar to full-fat/full-sugar versions.

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Chapter I

INTRODUCTION

Soft wheat flour attributes are important to the quality of baked goods. A baker or food manufacturer must procure flour that will produce the highest quality end products. Flour specifications include percentage ash, flour pH, particle size, and protein content. Although many of these flour traits are influenced by crop year, location, cultivation practices, environmental and genetic variation (Gaines and others 1996), the miller can still design flours of high quality and specific end-uses.

Biscuits, cakes, cookies, and pastries are a few of the many types of soft wheat bakery products. Within these product lines, reduced-calorie versions are available, which meet consumer demands for healthier fare and specialty dietary products. Seventy-five percent of Americans consume a low-fat food every 2 wk and 60% consume a "light" product according to a 14-d, 5200-volunteer diet survey (Katz 1998). Development of these reduced-fat and sugar bakery goods is a difficult task for the formulator. With the removal of fat and/or sugar in part or whole and the introduction of fat replacers and sugar replacers, flour quality, such as protein content, may become more significant to final product quality.

Researchers have extensively investigated the influence and importance of protein content, protein quality, and protein composition of hard wheats and flour to bread-making potential (Gupta and others 1992). Hard wheats, high in protein (9.6-14.8%) and low in starch content, produce flours possessing the necessary gluten strength for yeast-leavened pan and hearth bread production. Soft wheats, on the other hand, are grown in areas of high rainfall and low soil fertility and produce flours of high starch and low protein (8.8-11.1%) contents (Pyler 1988). These characteristics, along with other flour attributes, make soft wheat flours suitable for finely textured bakery products. Limited research on soft wheat flour attributes has been reported and the relationship of protein content to soft wheat product quality is minimally understood.

Although low protein contents are ideal for limited gluten development in soft-wheat bakery items, it is likely a mistake to view the proteins as functionally inert (Gaines 1990). During baking, cookie dough forms a continuous network because flour proteins swell, water mobility decreases, and dough viscosity increases as the glass transition temperature is reached; these events continue until cookie spread eventually stops (Doescher and others 1987). Higher protein content causes final cookie spread to set early, resulting in smaller cookies. Another theory explains that protein in high quality flours will exhibit viscous expansion and creep followed by structure collapse, but poor flours expand then shrink (Slade and others 1989). This shrinkage results in reduced cookie spread.

Baking tests are often used to study flour quality. The American Association of Cereal Chemists has published several product specific baking tests that can be used for different flour categories (AACC 2000). Specific formulas for angel cakes, high ratio cakes, leavened biscuits, sugar-snap and wire-cut cookies have been developed to test angel cake, cake, biscuit, and pastry flours, respectively. Differences in standardized measurements can then be indicators of flour baking quality. For example, cookie/pastry flour quality is assessed using the sugar-snap and/or wire-cut cookie method, in which width (W), thickness (T), and spread factor (W/T ratio) are determined; larger values for width and spread factor indicate better flour quality (Kaldy and Rubenthaler 1987).

These baking tests have been utilized to investigate influence of protein content of soft wheat flour on baking performance, and a relationship has been shown to exist for cookie flours. Labuschagne and others (1997) reported that cookie diameter will increase with lower protein contents. Gaines (1985) also found a significant but weak negative correlation between cookie diameter and flour protein content. Since small variations in protein exist, the relationship between protein content and baking quality of soft wheat flour needs further confirmation.

The bakery industry has many market interests to watch. Today, consumers demand convenience, taste, nutrition, and price, without sacrificing quality (Kohn 2000). The baking industry has responded to consumer trends as evidenced by the increased growth in wheat and wheat product consumption. Per capita use of flour and cereal products increased to 200 pounds in 1997 from an annual average of 145 pounds in 1980 (Putnam and Allshouse 1999). This increase is attributed to the increase in convenience bakery items and a burgeoning consumer interest in nutrition.

Americans still eat too much fat and consume an average of 2000 calories per day compared to 1800 in 1970 (Anonymous 1998). The current Dietary Guidelines for Americans promote 6-11 servings a day of grain-based foods and moderation of fat and sugar intake (USDA/USDHHS 2000). As a response to health and diet recommendations to consume a low-fat diet for weight management and prevention of disease, new fat replacers and bulking agents for sugar replacement are readily available to the industry (Akoh 1998).

The Calorie Control Council of Atlanta reports that more people link "lite" foods and beverages to a personal goal of "staying in better overall health" (Anonymous 1998). Some sources indicate that interest in fat-free and reduced-fat products is declining, but successful reduced-fat brands continue to hold a strong market position (Kohn 2000). Consumer views on reduced-fat bakery products include "bland or boring packaging" and "poor taste and mouthfeel experiences" (Anonymous 1998; Mendola 1997). On the other hand, high hedonic ratings and acceptability can be sustained over extended use once the initial product acceptance is made, as seen in a 12-wk home-placement study with reduced-fat chocolate and sausage products (Stubenitsky and others 1999). Use of fat and sugar replacement ingredients in bakery products offers dietary options for individuals who strive to consume reduced-fat and sugar diets; therefore continued research and development work is warranted to ensure that high-quality reduced-calorie products are produced.

Fat and sugar have important structural, textural, and flavor functions in a bakery product. A lack of knowledge regarding functional properties of fat and sugar replacers and the interaction of these ingredients have been key to technical difficulties in production of reduced-fat and lower sugar products (Anonymous 1998). The task is becoming easier as improved replacements systems are introduced. To date, researchers have investigated which fat mimetic or sugar replacer performs best and what level of replacement will result in the highest consumer acceptability in a specific product (Armbrister and Setser 1994; Olinger and Velasco 1996; Sanchez and others 1995). How these ingredients interact with the other ingredients, specifically the flour, and how flour quality might impact the incorporation of these ingredients have not been explored. It is hypothesized that small differences in flour protein content may influence the level of calorie reduction and the type of fat and/or sugar replacer used.

Cookies, a popular commercial product, are available in many varieties, including reduced-fat and sugar options. Formulation parameters such as flour quality and sugar, fat, and moisture levels characterize the different types of cookies and their production method used (e.g. wire-cut, deposit, rotary-molded, etc.). Extensive research confirms that flour quality will impact cookie quality. Cookie flour is generally 7.5-8.5% protein and 0.38-0.42% ash with a pH of 5.8-6.0 and produces a spread factor of 9-10, but stronger flours (higher protein contents) are commonly used (Pyler 1988). Reduced spread occurs with these stronger flours, while an increase in shortening and sugar is used to retain optimum tenderness (Pyler 1988). Therefore, in formulas that are intentionally reduced in fat and sugar, flours of the lowest protein content may produce the highest quality cookies.

Low-moisture and high levels of fat and sugar in the cookie system present a challenge for the reduction of sugar and fat in the cookie system. A balance between toughening (flour, water) and tenderizing (sugar, fat) agents achieves optimum texture in cookies. Fat functions to coat the flour particles which limits formation of a continuous network of starch and protein (Sanchez and others 1995). A competition for water by the high sugar content delays and minimizes starch gelatinization and gluten development during mixing.

When fat is reduced or omitted, cookie dough is difficult to handle, spread is reduced, and a compact, hard product results (Hoseney 1986; Manley 1991). Chewy textures, intermediate moisture contents, and a non-traditional snap characteristic have also been noted in reduced-fat cookies (Vetter 1993). Conflicting results have been found for fat-reduced cookie systems. As fat reduction increased from 20 to 60% using a polydextrose fat replacement, cookie spread significantly decreased in vanilla shortbread cookies (Hodgson and others 1993). In another study using polydextrose, chocolate-chip reduced-fat cookies had significantly larger spreads with the highest fat replacement of 75% (Armbrister and Setser 1994). Differences in formulations, mixing methods, and flour quality may account for the different results between these 2 studies.

Besides polydextrose, many other fat replacers are available on the market and include protein-based, lipid-based, and a multitude of carbohydrate-based mimetics. The physical properties of each type of fat replacer and the interactions among all the ingredients in the cookie system, which includes flour, are key to selecting the most ideal fat-replacement.

Sugar content is also critical to cookie structure. Starch gelatinization of cookie dough has been shown to vary with sucrose concentration. When sugar is decreased from 60 to 50, 40, and 30% sucrose, starch gelatinization temperatures are lowered, resulting in earlier gelatinization and smaller cookie spreads (Abboud and Hoseney 1984). More water would also be free to interact with the flour proteins, thus increasing gluten development.

Sucrose-to-protein ratio differences have been shown to affect cookie spread and set-time rates. At equal sucrose and flour levels, the ratio of sucrose to flour protein will be greater in a soft wheat flour dough than in a hard wheat flour dough. Therefore soft wheat flours have delayed cookie spread and set-time resulting in larger diameters (Miller and Hoseney 1997). When sugar is reduced in a cookie dough, and bulking agents are added, possible interactions between the sugar system and flour protein in soft wheat baked goods may occur. To date, investigation of this has not been reported.

This research was conducted to explore the impact soft wheat flour protein level on final product quality in wire-cut cookies formulated with 3 fat replacers at 3 levels of reduction and 3 sugar replacers at 2 levels of reduction. This study was divided into two parts. Part 1 investigated all treatment combinations using a micro wire-cut cookie method and Part 2 examined selected formulas from Part 1 that were scaled up to a macro wire-cut cookie method for sensory and instrumental evaluation. The overall objectives of the study were:

1. To investigate the effect of flour protein content, fat replacer and level, sugar replacer and level, and the interactions among these variables on cookie spread.

2. To determine if differences in instrumental cookie hardness, if present, are attributable to flour protein content, fat replacer and level, and sugar replacer and level, and the interactions among these variables.

3. To determine if flour protein content influences the extent of fat and/or sugar reduction that can be achieved in a wire-cut cookie formulation.

4. To develop a lexicon of cookie attributes that could be utilized for sensory evaluation of the standardized wire-cut cookie method.

5. To use sensory evaluation of the wire-cut cookies to examine if differences in flour protein level and the addition of fat replacers and sugar replacers will affect cookie appearance, texture, and flavor.

6. To examine correlations of sensory measurements of textural attributes and baked color with instrumental values of cookie hardness and color values (L^*, a^*, b^*, and Hue angle) respectively.

Chapter II

REVIEW OF LITERATURE

Soft Wheat Flour and Baking Quality

Baking performance of soft wheat flour is of vital concern to the baking industry. Factors such as cultivar, region of growth, environmental factors over growing periods, and harvest time affect baking performance of soft wheat flours. Although select cultivars are grown today to achieve improved traits and higher wheat yields, the miller must still blend flours to meet specifications that meet bakers' and manufacturers' needs (Posner and Hibbs 1997). These specifications may include protein content, flour pH, percentage ash, and specific rheology standards.

Cakes, angel food-cakes, cookies, crackers, pretzels, doughnuts, biscuits, and noodles are products containing soft wheat flour that do not require a developed structure during fermentation (Posner and Hibbs 1997). Soft wheat flours are usually classified by predominant end-use, and milling practices are adapted accordingly. For example, a patent flour such as cake flour, is a composite of flour streams with the best color and lowest ash contents. Therefore, stream selection is critical. Cake flours are pin-milled or air classified into mainly starch granules and granulation is controlled. Finer granulation is ideal for angel-food cakes. Pound cakes and other lower-grade cakes use coarser cake flours (Posner and Hibbs 1997).

Cookie flour is a 100% straight-grade flour, and protein content is controlled. Cookie flour is generally 7.5-8.5% protein and 0.38-0.42% ash with a pH of 5.8-6.0 (Pyler 1988). Protein contents of 9-10% have also been reported as common for cookie production (Posner and Hibbs 1997). Millers use softer grinding practices and sifting with larger sieve apertures to achieve the desired protein contents, break flour yields, ash values, alkaline water retention capacity, and particle size. Each of these factors has been correlated with baking quality of cookies (Posner and Hibbs 1997).

Flour Protein Content

Determining predictors of baking quality of soft wheat flour is an important goal of researchers of soft wheats, millers, and bakers. Therefore, protein content of soft wheat flour has been investigated and researchers have found conflicting results. It has been shown that as flour protein content increases in straight-grade flour, cookie diameter decreases. Gaines (1985) confirmed this inverse relationship in a study of 219 straight-grade flours; however a weak correlation existed ($r = -0.32$, $p = 0.001$). The author concluded that ideal cookie tenderness and large diameters were attributed to flours that contained low protein, weak gluten, and small particles, and produced high break flour yields. Break flour yield is the amount of flour extracted after crushing by the break rolls; high yields indicate high quality wheats. In another study, Kaldy and Rubenthaler (1987) showed a strong correlation of protein content to cookie diameter. Soft spring wheats were compared to soft winter wheats. The spring wheats yielded smaller cookies, and protein content of the spring wheats was significantly correlated with cookie diameter ($n = 15$, $r = -0.71$, $p \leq 0.01$).

Environmental and genetic differences of soft wheats produce inherent variation in flour protein content (Gaines 1991a). Soft wheat flours are generally milled from selected wheat composites that will produce the best quality flour(s). Therefore, single cultivars and/or blends of several cultivars are studied to find which flour attributes will provide the best prediction of flour quality. Gaines (1990) examined 58 soft-wheat cultivars that were milled into 64 straight-grade flours. A weak correlation was found between cookie diameter and protein content of the flour ($r = -0.27$, $p = 0.05$); however when protein content was combined with break flour yield and alkaline water retention capacity (AWRC), protein content was considered a good predictor of cookie diameter. AWRC is the percentage of water retained by the flour components following alkaline water suspension and centrifugation. Low AWRC values have been correlated with large cookie diameters.

When one cultivar was studied, protein content was found to have a significant effect on cookie diameter and hardness (Gaines and others 1992a). One Caldwell cultivar was milled into 4 flours of different protein contents (6.9, 8.1, 9.0, and 10.0%). When measured by Instron probe resistance, the 6.9 and 8.1% protein flours produced cookies that were similar in hardness but both were significantly softer than the two higher protein flour cookies. The 10% protein flour produced the smallest and thickest cookies which were also significantly harder than the 8.1% protein flour cookies.

In order to understand the role protein plays in baking performance of a flour, hard and soft wheats have been compared because the soft, tender characteristics of cookies, cakes, and pastry products will not occur when hard wheat flours are used in place of soft wheat flours. Miller and Hoseney (1997) reconstituted starch fractions of a soft wheat flour with the water solubles and/or gluten fractions of a hard wheat flour in a fractionation/reconstitution study. When the reconstituted flours were used in a sugar-snap cookie formula, cookies became smaller when the soft wheat starch fraction was combined with the water soluble and gluten fractions from the hard wheat flour. Cookie size remained unchanged when only 1 hard wheat fraction was combined with 2 soft wheat fractions. Yamazaki and others (1977) also showed that 2 hard wheat fractions reconstituted with 1 soft wheat fraction would decrease cookie diameter.

A fractionation and reconstitution study has also been used to understand which flour fractions in a soft wheat flour (gluten, tailings, water-solubles), together or in combination, impact baking quality the most. Donelson (1988) substituted prime starch (g/g) for either the gluten, water solubles, or starch tailings fractions. He found that when the gluten fraction was replaced, cookie diameter increased or remained unchanged. Gaines and others (1992a) also showed that some flour fractions were more critical to cookie quality. The gluten fraction or the combination of the gluten fraction with other fractions (tailings, water solubles) contributed more to cookie hardness than did the starch, lipid, and tailing fractions. The authors also pointed out that as the hydrophilicity of each flour fraction increased, cookie hardness increased.

Other Flour Attributes

Along with flour protein content, other flour attributes have been investigated. Moisture content, AWRC, percentage ash, flour pH, and mixing characteristics as measured by a mixograph are other attributes a baker may specify. Many of these attributes, when combined with flour protein content, can predict cookie diameter (Gaines 1990).

Flour moisture contents above 15% can support fungal growth. Therefore, this level has been established as the accepted maximum level. Besides a decrease in storage stability, increased moisture contents can increase shipping costs for the baker. Alterations in dough absorption can also occur which ultimately affects dough handling properties (Pyler 1988).

Percentage ash, which represents the totality of the mineral elements absorbed by the plant from the soil, is commonly specified by bakers. The bran portion of wheat is higher in ash than the endosperm. Therefore, ash reflects the degree of endosperm separated from the bran during milling (Pyler 1988). Although low ash values generally indicate a flour of high quality, ash cannot serve as an overall index of flour quality (Kaldy and Rubenthaler 1987; Pyler 1988). Cookie flour ash contents ranging from 0.33 to 0.47% are acceptable (Matz 1992).

Alkaline water retention capacity (AWRC) was developed as a predictive test of baking quality for soft wheat flours and is directly correlated with cookie diameter, without adjustments for protein or ash contents (Yamazaki 1953; Kaldy and Rubenthaler 1987; Posner and Hibbs 1997; Hoseney and Rogers 1994). The AWRC test is based on the fact that hydration of gluten proteins will take place in acid solutions but not under alkaline conditions. Leavening agents contribute to the alkaline nature of cookie doughs and therefore when flours with low AWRC values are used, little water is retained; these doughs require less heat during baking to remove water (Posner and Hibbs 1997). For cookie flours, AWRC values of 52-53% have been accepted as high quality (Posner and Hibbs 1997). Although low AWRC values are considered desirable, it has also been suggested that consistent values from lot to lot should also be a priority (Anonymous 2001).

A mixograph can be used to evaluate different types of flours and the effects of added ingredients on dough rheology and mixing properties (AACC 2000). Values obtained from a mixogram include angle of development, angle of breakdown, peak height, and time to peak height. Optimum dough absorption level of a flour is also determined. This mixograph absorption value reflects the optimum amount of water that is required to produce a dough of desirable consistency for handling and baking performance (Finney and Shogren 1972). Low absorption values are desired because less water will be retained by the flour when a cookie dough is produced. Cookie spread rate will be faster and set-time will be delayed. Mixograph absorption values between 52-58% have been reported as ideal (Anonymous 2001). Mixogram curve height is directly proportional to protein content and inversely proportional to flour absorption properties (Pyler 1988). This peak height value is used to predict protein strength for soft wheat flours (Finney and others 1987). Angle of development and breakdown are indicators of flour hydration rate and tolerance to over mixing, respectively.

Dietary Fat and Sugar

A diet low in fat, saturated fat, and cholesterol is a key recommendation of the Dietary Guidelines for Americans (USDA 2000). Total dietary intake of fat has declined from 37-38 to 33% of total energy (Mattes 1998). However, only 32-34% of American adults meet the fat intake goal of less than or equal to 30% of total calories (Mattes1998). It is well known that excessive fat intake is linked to many chronic diseases such as cardiovascular disease, hyperlipidemia, hypertension, a higher incidence of colon cancer and other cancers, digestive disorders, and adult onset diabetes (Kuller 1997). Extensive research also supports a link between fat consumption and energy intake with obesity in both adults and children (Kennedy and Bowman 2001).

Many fat-reduced processed foods are available as added dietary options to help one achieve a lower-fat intake. Based on results of 1996 USDA Continuing Survey of

Food Intakes by Individuals, Kennedy and Bowman (2001) reported that high users of fat-modified foods were more likely to have a diet providing less than 30% of calories from fat. This warrants continued product development and refinement of fat-reduced foods.

Nutritive sweeteners, which satisfy our innate liking for sweetness and provide energy, have also been blamed for increased incidence of obesity, cardiovascular disease, adult onset diabetes, dental caries, and behavioral disorders (Duffy and Anderson 1998). Use of reduced sugar or no sugar chewing gums has been shown to reduce the risk of dental caries; sugar-free beverages are also a staple for persons with diabetes because high intensity sweeteners do not produce the glycemic response as seen with sugar-sweetened counterparts (Duffy and Anderson 1998).

Although a link between sugar intake and heart disease has not been substantiated, increased plasma triglycerides have been linked to excessive sucrose or fructose intake (Duffy and Anderson 1998). Increased consumption of sugar, often without an increase in food volume, generally results in energy intake exceeding expenditure thus contributing to weight gain and possibly obesity. Duffy and Anderson (1998) also suggested that added sugar in foods can increase volume of consumption for hedonic reasons. Weight gain and increased triglycerides can thus increase the risk for cardiovascular problems. Although the availability and increased consumption of non-nutritive sweeteners has not reduced the incidence of obesity in the American population, studies have shown that long-term weight loss maintenance has been facilitated with the use of these sugar substitutes (Blackburn and others 1997).

Fat Replacers

Food scientists still seek the ideal fat replacer that contributes both the flavor and functions of a traditional fat in a food product. Fat serves as a carrier of lipophilic flavor compounds, flavor stabilizer, and a source of concentrated energy (9 kcal/g), fat soluble vitamins, and essential fatty acids. In bakery products, fat is key to mouthfeel, aroma/odor properties, tenderness, flakiness, perceived moistness and oiliness, and overall structure.

To replace fat in a bakery item, reformulation using lipid, protein, or carbohydrate-based fat replacers, either alone or in combination, must be done. It has been suggested that sensory textural perceptions of high fat levels can be achieved when macromolecule substitution meets certain factors. First, the size of the particles should be in the size range of fat crystals (20-30 µm) to promote deformable gel formation and thus a short texture; second, water binding or water structuring function must be present to impart the perceived moistness (Setser and Racette 1992). A 3-ingredient system has also been suggested for a good fat mimetic in bakery products. Glicksman (1991) recommends a thickening agent for lubricity and flow control, a soluble bulking agent for adsorption/absorption of the food for good taste reception, and a microparticulate, generally insoluble, which acts like a ball bearing to create smoothness.

Fat replacers are commonly grouped as fat substitutes or fat mimetics. Fat substitutes are macromolecules that physically and chemically resemble triglycerides. Substitutes that replace fat on a one-to one, gram-for-gram basis are fatty acid-based and lipid-like, and are chemically synthesized or derived from conventional fats or oils through enzymatic modification (Akoh 1998). Fat mimetics are substances that imitate organoleptic or physical properties of triglycerides but which cannot replace fat on a equal weight basis. Generally, fat mimetics are called protein or carbohydrate-based fat replacers. Common food ingredients such as starch and whey proteins are modified to mimic the functions of fat.

Fat Substitutes

Sucrose polyesters, produced through interesterification of sucrose with 6-8 long-chain fatty acids (8-22 carbons), are one type of lipid analog that can replace oils/fats in high-heat applications including deep-fat frying and baking (Setser and Racette 1992). The type of fatty acids used governs the functionality, physical properties, and potential applications. Sucrose polyesters are non-caloric because the large size of the molecule and the number of nonpolar fatty acid constituents prevent digestion, intestinal absorption and metabolism. Olestra® (Proctor and Gamble Co., Cincinnati, OH) has been approved by the FDA but considerable debate over the safety of this fat replacer still remains. It is thought that Olestra causes increased gastrointestinal effects (i.e. cramping and stool softening or loosening) and decreased absorption of fat-soluble vitamins (Akoh 1998). The FDA still requires a warning statement on the food label to inform the consumer about these possible risks. These risks may be outweighed by the possible benefits to some population groups. People at high risk of coronary heart disease, obese individuals, and colon cancer patients, can lower total fat intake, lose weight, and lower blood cholesterol with consumption of Olestra® containing products (Glueck and others 1994). Currently Olestra® is approved for use in savory snacks.

Other fat substitutes include caprenin, Salatrim/Benefat™, and emulsifiers (Akoh 1998). Caprenin (Proctor and Gamble Co., Cincinnati, OH), or caprocaprylobehenic triacylglyceride, is available for use as a confectionary fat in soft candy and confectionary coatings. Caprenin is produced by esterification of gycerol with caprylic (C8:0), capric (C10:0), and behenic (C22:0) fatty acids, is partially absorbed and provides only 5 kcal/g. Salatrim/Benefat™ is a structured lipid comprised of at least one short chain and one long chain fatty acid randomly attached to glycerol. Partial absorption of Salatrim™ results in 5 kcal/g and the functional properties (e.g. melting point, hardness, appearance) differ based on the number of short and long chain fatty acids. Chocolate-flavored coatings, caramels and toffees, bakery fillings, dips and sauces, frozen dairy desserts, and cheese are applications of Salatrim™.

Emulsifiers include sucrose fatty acid esters, mono- and diglycerides, sodium stearoyl-2-lactylate, lecithin, and polyglycerol ester. Up to 50% reduction of fat in a formulation can be acheived with the use of emulsifiers. Hydrophilic and lipophilic properties enable the emulsifier to stablize the interface between fat and water droplets through hydrogen bonding. When used with other ingredients, emulsifiers can enhance the fat replacement system by stabilizing aeration and foaming, increase lubricity, modify fat crystallization, prevent syneresis, and improve rheology. Emulsifiers are useful in baked goods, margarines, frozen desserts, dairy products, spreads and shortenings, processed meats, and confections.

Fat Mimetics

Carbohydrate-based Mimetics

Partial or total fat replacement has been accomplished with different carbohydrate-based fat replacers which include a variety of ingredients derived from gums, starches, celluloses, maltodextrins, modified polymers of glucose, or hydrolyzed fibers. Most carbohydrate fat replacers function by incorporating water into gel-type structures that emulate the properties bestowed by fats. This suggests that products made with them will have increased final moisture content but not necessarily a higher water activity (a_w). Corn syrups, syrup solids, high-fructose corn syrups, and polyols (e.g. sorbitol, maltitol) are often added to reduced-fat formulations to help control a_w. Carbohydrate replacers are not suitable to frying, but can be used as fat barriers for frying and for baking (Akoh 1998).

Gums, or negatively-charged, high-molecular-weight carbohydrates, will contribute thickening, gelling, and stabilizing properties. Guar, xanthan, locust bean gum, carrageenan, gum arabic, and pectins are all gums incorporated into reduced-fat salad dressings, icings and glazes, desserts and ice cream, ground beef, baked goods, dairy products, soups, and sauces. The slippery mouthfeel of oil can be achieved through the use of starches. Sources of starch-based mimetics include corn, waxy maize, wheat, potato, tapioca, rice, and waxy rice and often these native starches are modified to improve functional and sensory properties.

Maltodextrins are nutritive polysaccharides derived from corn starch, generally recognized as safe (GRAS), and do not require FDA approval (Akoh 1998). "Maltodextrin" or "corn syrup solids" are ingredient names on food labels familiar to consumers, making maltodextrins a favorable fat mimetic. The dry form of maltodextrins is commonly used to add solids when fat is removed from a formulation. Maltodextrins contribute 4 kcal/g and enhance ingredient dispersion in dry mixes, spreads, and cream fillings. As a gel, a 25% maltodextrin heated and cooled solution can mimic the texture of hydrogenated shortening, will contribute only 1 kcal/g, and can act as a 1:1 fat replacement in baked goods, extruded snacks, salad dressings, and spreads (Nonaka 1997).

Polydextrose, a water-soluble, randomly-bonded glucose polymer containing sorbitol and citric acid, is marketed as a bulking agent useful in fat replacement (Hodgson and others 1993). With 60% of the molecule passing through the gut unabsorbed, polydextrose provides 1 kcal/g. It has been approved as a bulking agent, formulation aid, humectant, and texturizer in food applications (Moppett 1991). Applications include baked goods, bakery mixes, chewing gum, confections, frostings, salad dressings, syrups, and other food categories. A potential laxative effect of polydextrose requires the labeling of food products containing more than 15 g polydextrose per single serving must state: "Sensitive individuals may experience a laxative effect from excessive consumption of this product" (Giese 1993).

Oatrim® or Betatrim® is made by partial enzymatic hydrolysis of the starch-containing portion of the hull or bran and obtained from whole oat and/or corn flour. It was developed and patented by the U.S. Department of Agriculture's National Center for Agricultural Utilization Research and is licensed to ConAgra (Omaha, NE), Quaker Oats (Chicago, IL), and Rhone-Poulenc (Cranbury, NJ). Oatrim® has been successfully used in dairy products, confections, frozen desserts, baked goods, cereals, and meat products. Nutritionally it provides 4 kcal/g as a dry powder, 1 kcal/g as a hydrated gel with 3 parts water, and 5% β-glucan (Inglett and others 1994). β-glucan has been documented to have anti-cholesteremic properties (Ripsin and others 1992). Oatrim® has the mouthfeel of regular triglycerides and is thermally stable in retort processing conditions and other short-time high temperature applications, except frying. Z-trim, another USDA created fat mimetic, is an indigestible insoluble fiber from the high-cellulose portion of corn or wheat brans or the hulls of oats, soybeans, peas, and rice. Designed to be used with Oatrim®, Z-trim® provides additional dietary fiber and contributes moistness, density, and smoothness in many food applications.

Protein-based Mimetics

Milk protein and/or milk solids (e.g. skim milk or low-fat milk) are simple protein-based fat replacers. Today, manufactured fat replacement ingredients from protein sources include whey protein concentrates, whey protein isolates, gelatin, soy protein, microparticulated whey, egg or milk protein products, and protein blends with gums and starches (Miraglio 1995). Protein-based fat replacers provide many of the same characteristics as carbohydrate-based replacers, but contribute added functionality to food systems including opacity and emulsification (Miraglio 1995).

Microparticulated whey protein is prepared from whey protein concentrate and is marketed as Simplesse® (Miraglio 1995). Simplesse®, initially approved for use in dairy desserts, is now approved for use in cheeses, sour cream, salad dressings, mayonnaise, creamers, baked goods, and sauces (Artz and Hansen 1994). Three grams of Simplesse® contain approximately 1 g of protein providing approximately 1.33 kcal/g (Gaull 1991). Additionally, hydration of the fat replacer within specific applications can reduce calories further.

Sugar Replacers

Alternative sweeteners include sugar substitutes and sugar replacers. Substitutes, or the popularly consumed high-intensity sweeteners (HIS), function to replace the sweet taste of sucrose. Sugar replacers may not be as sweet as sucrose but can replace the volume, textural, and mouth-feel properties of sucrose in many bakery, dessert, confectionary and beverage type products. Noncariogenic properties, reduced calories, and glycemic control are primary benefits of sugar substitutes and replacers. Confections, hard candies, lozenges, syrups, chocolates, bakery products, and beverages are a few of the products in which alternative sweeteners have been successfully incorporated.

Alternative sweeteners are often selected based on whether they meet safety and regulatory status, taste or taste quality, solubility, stability in the food product, and cost to the manufacturer (Giese 1993; Dubois 1992). Sweeteners are regulated by the 1958 Food Additives Amendment to the Food, Drug, and Cosmetic Act and must be Generally Recognized as Safe (GRAS). GRAS status indicates the ingredient has been judged safe by "....experts qualified by scientific training and experience to evaluate the safety of substances directly or indirectly added to food. The basis of such views may be either (1) scientific procedures or (2) in the case of substances used in food prior to January 1, 1958, through experience based on common use in food" (FDA 1992).

An attempt has been made to define taste quality of a sweetener based on a structural proton donor/proton acceptor model, but sensory evaluation of a sweetener in a specific food has proven to be the best approach (Giese 1993; Shallenberger and Acree 1967). HIS can be used in low concentrations to achieve the desirable sweetness, however, each sweetener is compared on a cost basis to sucrose by dividing the cost per pound by the sweetness potency at the desired sucrose equivalency rate. It is also important that a HIS has excellent water solubility and is stable under adverse conditions (Dubois 1992; Giese 1993).

Development of reduced-sugar products is not as easy as simply replacing sucrose with an equi-sweet amount of alternative sweetener. In many products, sugar functions to add volume and texture as well as sweetness. High intensity sweeteners (HIS), such as aspartame and acesulfame-K (Ace-K), lack the bulking properties that other sugar replacers can contribute. Therefore, formulation of reduced-sugar foods may require a blend of HIS and sugar replacers such as sugar alcohols, maltodextrins, polydextrose, or cellulose.

Blends of two or more sugar substitutes and/or replacers have been used to achieve the most ideal sweetness and textural characteristics (Portmann and Kilcast 1998; Verdi and Hood 1993). For example, Noble and others (1991) reported no non-sweet side tastes for an aspartame-acesulfame-K blend in an aqueous solution. In a separate study, a synergistic effect was seen in maltitol-cyclamate, maltitol-acesulfame-K, and sucrose-cyclamate sweetened mineral water solutions evaluated descriptively by a 13-member sensory panel (Portmann and Kilcast 1998). The authors concluded that sweetness intensity was enhanced, but the persistence of sweetness did not occur as seen with single-use sweeteners, such as aspartame. Also, there was a considerable reduction of undesirable side-tastes and aftertastes.

Sugar Substitutes

Alternative sweeteners, high-intensity sweeteners, and sugar substitutes are interchangeable names that have been used to describe ingredients that attempt to mimic the sweet taste of sugar. Saccharin, acesulfame-K, and aspartame are three approved sweeteners in the United States. Cyclamates, once with GRAS status, are now banned due to a possible link to tumor growth (Price and others 1970).

Saccharin, an organic petroleum compound, is 200-700 times sweeter than sucrose. It is available in three forms, an acid saccharin, sodium saccharin, and calcium saccharin. It is a cost-efficient sweetener that can be used in a multitude of products including beverages, baked goods, jams, toppings, chewing gum, and confections. A bitter metallic aftertaste is one disadvantage of saccharin and its safety has been a controversial struggle. Following the FDA ban on saccharin use in 1977, a congressional moratorium required a health warning label indicating this substance as a possible carcinogen. Although the warning label is still required, the ban on saccharin use has been lifted (FDA 1991).

Acesulfame, or 5,6-dimethyl-1,2,3-oxthiazone-4(3H)-one-2,2-dioxide, was discovered accidently in 1967 by Karl Clauss and Harold Jenson of Hoechst AG Laboratories. The potassium salt of acesulfame is known as acesulfame-K and is marketed as Sunette® (Nutrinova Inc., Somerset, NJ). In 1988, the United States approved Ace-K for use in chewing gum, beverages, dry beverage mixes, baking applications, and as a tabletop sweetener. Ace-K is 200 times sweeter than a 3% sucrose solution with some noted bitter and metallic aftertastes at high concentrations. A synergistic enhancement of sweetness has been observed in 1:1 by weight mixtures of Ace-K and aspartame. FDA has set an ADI of 15 mg/kg (Duffy and Anderson 1998).

Aspartame is a dipeptide of the methyl ester of L-phenylalanine linked to L-aspartic acid, or aspartylphenylalanine. It is currently marketed as NutraSweet® (NutraSweet, Inc., Mount Prospect, IL) and is available as a tabletop sweetener. Safety testing has been conducted on aspartame for over two decades and FDA approved the substance in 1996 (Duffy and Anderson 1998; Dubois 1992) . Digestion will hydrolyze aspartame into aspartic acid, methanol, and phenylalanine. The amino acids are thus metabolized to provide 4 kcal/g (Duffy and Anderson1998). Since aspartame is 160-220 times sweeter than sucrose, low concentrations can be used, making this caloric contribution negligible. Foods containing aspartame must include a warning statement for people with phenylketonuria, who lack the enzyme needed to metabolize phenylalanine. Aspartame is not stable in acidic conditions and will lose its sweetness under prolonged heating. A hydrogenated vegetable coating has been used to coat aspartame for delayed release of the sweetener properties in baking applications (Giese 1993).

Sucralose, a new alternative sweetener, recently received FDA approval in April 1998 as a tabletop sweetener and for use in a number of desserts, confections, and nonalcoholic beverages. This white, crystalline, non-hygroscopic solid, marketed as Splenda® (McNeil Specialties, Inc., New Brunswick, NJ), is produced by selective chlorination of the sucrose molecule (Duffy and Anderson 1998; FDA 1999). Three atoms of chlorine are substituted for hydroxyl groups in the sugar molecule. Sucralose is 300-1000 times sweeter than sugar, highly water soluble, and stable at high temperatures and in acidic environments. These latter properties make it ideal for baking and carbonated soft drink applications, respectively. Sucralose can withstand temporary manufacturing delays, will not interfere with yeast fermentation, and will withstand extreme mixing or baking procedures without the loss of sweetness (Chapello 1998). Prolonged storage at elevated temperatures or in highly acidic environments can cause sucralose to eventually breakdown (FDA 1999). Sucralose is excreted in the urine unchanged, provides no energy, and the ADI has been set at 5mg/kg body weight per day (Duffy and Anderson 1998; FDA 1999).

Bulking Agents

Today a variety of bulk sweeteners is available to the baking industry, permitting the development of reduced-calorie, no added sugar or sugar-free products. These bulk sweeteners give alternatively sweetened baked goods the texture, sweetness, and mouth-feel of their sugar-sweetened counterparts (Olinger and Velasco 1996).

Polydextrose, a randomly bonded melt condensation polymer of dextrose, is nonsweet and low calorie (1 kcal/g); it can replace fat and/or sugar and serve as a carrier ingredient (Moppett 1991). It has been successfully utilized as a bodying or texturizing agent in baked products. In solution, polydextrose has a slightly higher viscosity than sucrose at similar concentrations in solution. For this reason, the amorphous chemical compound contributes to improved mouth-feel and viscosity in many reduced-calorie (fat and sugar) products (Moppett 1991).

Sugar alcohols, or polyols, are a group of ingredients that are produced by the hydrogenation of the corresponding reducing sugars in which a hydroxyl group replaces a ketone or aldehyde group on the sugar molecule (Ellwood 1995). They can be classified as hydrogenated monosaccharides (e.g. sorbitol, mannitol, and xylitol), hydrogenated disaccharides (e.g. isomalt, maltitol, and lactitol), or mixtures of mono-, di-, and oligosaccharides (hydrogenated starch hydrolysates).

In the US, allowable sugar alcohols are listed by the FDA in the Code of Federal Regulations as an approved additive (e.g. mannitol) or have GRAS status (e.g. sorbitol). Products containing polyols can be labeled "sugarless", "does not promote tooth decay", and "not a reduced calorie food" (Giese 1993). However, most polyols offer some caloric reduction and can be combined with the high-intensity sweeteners to achieve desirable textural properties and sweetness levels. With the exception of xylitol, most polyols are considerably less sweet than sucrose (Ellwood 1995).

"Low digestibility" can be used to describe sugar alcohols; for this reason, energy values are difficult to estimate (Ellwood 1995). The substance is only partially or not at all absorbed in the upper part of the gastrointestinal tract. The non-absorbed portion of the substance is partially or completely fermented by normal colonic bacteria. This slower intestinal absorption makes polyols useful for dietetic diets, but a laxative effect can occur when polyols are consumed in large quantities (25-50 g/day) (Moppett 1991; Moskowitz 1991;Sträter and Irwin 1991; van Velthuijsen and Blankers 1991).

Some of the most commonly selected polyols used in bakery products include lactitol, maltitol, and isomalt. Lactitol has a clean sweet taste that closely resembles the taste profile of sucrose but has only 40% of the sweetening power of sucrose. It is produced by reduction of the glucose portion of the lactose molecule and has an estimated energy value of 2-2.6 kcal/g. Its nonhygroscopic properties prevent moisture absorption; therefore, products maintain crispness and shelf-life (van Velthuijsen and Blankers 1991). Lactitol is generally partnered with Ace-K, aspartame, or saccharin in low-calorie, low-fat and/or sugar-free ice creams, chocolate, hard and soft candies, baked goods, preserves, and chewing gums.

Maltitol, a crystalline polyol, is produced by the hydrogenation of maltose in the presence of a catalyst. This process forms maltitol syrup which can be dehydrated and crystallized into a dry powder form that possesses sensorial and technological properties similar to sucrose (Moskowitz 1991). Maltitol has a clean and pleasant sweetness, excellent heat stability, melting point similar to sugar, high solubility, high viscosity in solution, and no cooling effect attributable to a slight negative heat of solution. Maltitol has low hygroscopicity providing a lowering effect on water activity. Sucrose-free, chocolate-flavored confections are the most common application of maltitol. Toffees, jellies and jams, ice creams, and bakery products have also contained maltitol (Grenby 1996). Maltitol provides 2 kcal/g and is noncariogenic. A threshold of 100g/d intake has been noted to be intestinally tolerated (Giese 1993).

Isomalt, commonly used in hard candies, toffee, lollipops, fudge, wafers, and lozenges, has been available in the U.S. since 1990. An enzymatic action on sucrose rearranges the linkage between glucose and fructose producing isomaltose. Oxygen on either side of the fructose molecule is hydrogenated producing a mixture of glucomannitol and glucosorbitol, or isomaltulose. The reducing disaccharide is an odorless, white crystalline powder with half the sweetening power of sucrose and it has a lower cooling effect and hygroscopicity than other sugar replacers. Isomalt is highly resistant to acid and enzymatic hydrolysis and heat stable, making it ideal for many cooking, baking, and extrusion processes (Sträter and Irwin 1991). These properties also increase shelf stability of isomalt. Isomalt does not undergo the browning reaction, therefore no caramel taste is produced. This can be beneficial when utilizing it in specific flavored confections. Isomalt provides 2-2.4 kcal/g, and is anticariogenic, and suitable for persons with diabetes (Grenby 1996).

Other bulk sweeteners include cellulose, microcrystalline cellulose, carboxymethylcellulose, and methylcellulose. These are used in low-calorie food systems as bulking agents, binders, thickeners, and stabilizers. These compounds have GRAS status and have acceptable daily intakes of 0-25 mg/kg. Maltodextrins are nutritive saccharides with DE of less than 20, are nonsweet, and provide 4 kcal/g; these GRAS approved compounds are used primarily as bulking agents and binders.

The Cookie System

Classification and Types of Cookies

In industry classification of cookies is commonly based on how the dough is deposited onto the baking band. Dough formulations vary to meet these different processing techniques (Faridi 1990; Matz 1992). For example, rotary molded cookies are high in sugar and fat and low in moisture, resulting in little to no elasticity, which permits the dough to be forced into rotating molds, extracted, and deposited onto the band. Wire-cut cookie dough, similar to rotary molded, is extruded through an orifice and cut to size by a reciprocating wire. The dough must be short, yet cohesive to ensure a clean cut while maintaining its shape. On the other hand, cutting-machine cookies, require a high water content and a lower fat and sugar dough. This permits the dough to be worked into a continuous sheet, while sent through multiple sheeting rollers. Cutting-machine cookie method is least common in industry while the wire-cut cookie method is often used to study the physico-chemistry and processing concerns of the cookie system (Faridi 1990).

Ingredient Functionality

Low-moisture and high-sugar and shortening contents describe most cookie formulations. Each ingredient in a cookie system has an important functional role and slight changes in any ingredient can affect the final sensory properties of the baked cookie. Published research on functionality of cookie ingredients is not lacking. Researchers have investigated the effects of sugar content and type of sugar, shortening levels and type, formula moisture content, and variations in processing methods, such as mixing and baking times on the cookie matrix and quality.

Sugar restricts the development of gluten by competing for water, and the amount of sugar that will go into solution depends on the particle size of the sugar. Ultimately this influences the cookie spread and machining properties (Manohar and Rao 1997). Quantity, granulation, and type of sugar influence structure, texture, appearance, and flavor of short dough cookies. Manohar and Rao (1997) reported increased spreads, higher sensory scores (color, flavor, and surface), and crisper textures as sucrose level per kilogram of flour increased from 250 to 300 and 350 g. Abboud and others (1985) investigated the effect of sugar amount on cookie spread and quality. When a creaming procedure was used for mixing, increasing or decreasing the sugar content by 10% from the control of 60% (fwb) made no difference in cookie spread. When a non-creaming procedure was used, increased sucrose content resulted in larger cookie spreads. Finney and others (1950) reported similar results.

Coarse sucrose results in reduced cookie spread (Abboud and others 1985; Kissell and others 1973). Abboud and others (1985) investigated the effect of 2 sugar granulation sizes, superfine and granulated sucrose, on cookie quality. When the sugars were unsieved, both granulations produced cookies of similar size. When sieved, the granulated sucrose resulted in the smallest cookies.

Similar flavor characteristics, comparable sweetening power, and economic advantages make high fructose corn syrup (HFCS) an ideal sucrose substitute in cookies. Water content of the fructose syrup and the cookie formula must be considered when substituting HFCS for sucrose. A 60-75% HFCS partial replacement of the total sweetener will result in softer cake-like cookies and a 10-30% replacement will work in low-moisture, hard cookie formulations (Henry 1976). HFCS has been shown to increase dough stickiness, thus altering machinability (Curley and Hoseney 1984). These investigators also reported decreased cookie diameter and increased thickness as HFCS solids increased. Increased liquid contributed from HFCS may have caused faster cookie spreading during baking, but earlier cookie set time contributed to smaller cookie diameters. The higher moisture cookies also lacked desirable surface cracking and ideal snapping characteristics. HFCS altered the rate of surface drying, and sugar crystallization is thought to be inhibited by the presence of fructose and dextrose.

The third largest component after flour and sugar is the fat constituent of a cookie formulation. Fats may be the most important ingredients used in cookie manufacture. In doughs, fats perform shortening and textural functions by coating the flour surface, thus setting up a barrier between the aqueous phase and the fat. During baking the fat will melt creating a less hard, shorter product. Upon cooling the interaction of fat and sugar will delay setting of the syrup sugar solution into a hard vitreous mass. Type of fat, amount, and incorporation are important to the formulator.

Cohesiveness of the cookie dough was found to be related to level of shortening used. When fat content was decreased from 30 (fwb) to 25 and 20%, irregularly shaped cookies with coarse top grains were formed (Abboud and others 1985). Increased fat contents of 35% resulted in fine top grains, but diameter was not different from control (30% fwb). Type of fat (nonemulsified, emulsified, and nonemulsifed oil) did not affect the cookies.

Fat Replacers in Cookies

When fat is removed from a cookie formulation, texture, appearance, and flavor are affected. Fat contributes the necessary lubrication of the starch and protein components in a cookie dough which ultimately prevents the starch and protein from forming a continuous network. These shortened doughs result in a tender product. When fat is reduced, increased levels of water are needed to replace the high levels of fat. Fat replacers help stabilize this extra water. Researchers have found that cookies with non-traditional snap characteristics, chewy textures, and intermediate moisture contents will result when these fat replacers are incorporated (Vetter 1993). Glicksman (1991) also states that fat contributes the important "fatty mouthfeel" to a product. When fat is removed and replaced with other ingredients, product color can be altered. Degree of carbonyl-amine browning, as indicated by higher yellow intensities, was increased when carbohydrate-based fat replacers were used in cookies (Sanchez and others 1995).

Comparisons of fat replacement systems, both type and level of fat reduction, have been investigated to determine which system produces cookies with similar sensory properties to control full-fat counterparts. Hodgson and others (1993) investigated vanilla cookie formulas with 20, 40, and 60% polydextrose (Litesse®). As fat substitution level increased, dough handling became more difficult and shrinkage after baking occurred. Increased surface darkening was also noted by the significantly lower Hunter L* values and higher a* values found for the 60% polydextrose cookies. A 6-member trained sensory panel confirmed these changes in surface color and also found differences in surface cracking, hardness, chewiness, and moisture absorption. Higher moisture contents were found in the 60% polydextrose cookies; however more force was required to shear the cookies when the level of fat replacer increased. Panelists perceived the polydextrose containing cookies as harder. Sanchez and others (1995) also found that polydextrose retained the crispness associated with shortbread-type cookies. Hodgson and others (1993) concluded that the hygroscopic nature of polydextrose contributed to the higher moisture contents, but the increased carbohydrate-carbohydrate interactions caused the increased hardness values. Although differences were noted by the trained panel and through instrumental measurements, a consumer panel (n=35) rated the 20 and 60% Litesse® cookies similar in acceptability.

USDA developed hydrolyzed oat flour which is marketed as Oatrim® or Betatrim®. The fat replacer has been investigated for use in cookies. Inglett and others (1994) replaced margarine in an oatmeal raisin cookie at 50, 75, and 100% levels. A 20-member sensory panel noted a significantly lower sweet taste and higher cardboardy flavor in the 100% Oatrim® sample compared to the control. Texture was not significantly affected by Oatrim® addition; however, moistness was perceived to be significantly less than the control in the 75 and 100% Oatrim® samples. The 50% replacement had flavor characteristics and textural properties most similar to the control, and cookies made with 75 and 100% Oatrim® were rated significantly lower in overall quality by the panelists. Based on this study, anticholesterolemic properties and the feasibility of replacing at least half of the fat, make Oatrim® an ideal fat replacement system for cookie applications (Inglett and others 1994).

Oatrim® at 75 and 100% fat replacement levels in a peanut butter cookie was studied by Swanson and others (1999). Emulsifiers (diacetyl-tartaric esters of monoglycerides and sodium steaoryl-lactate) were combined with Oatrim® at 0.0, 0.1, and 0.2% (formula-weight-basis). Control cookies had the greatest spread and the 75% replacement with no emulsifier did not differ from the control. When either emulsifier was added, spread was reduced. These cookie doughs also exhibited a significantly lower pH. Lower pH of cookie doughs is associated with reduction in cookie spread (Pyler 1988). Color was also affected by the addition of a fat replacer but not by emulsifier type or amount. Higher L values were found in both substituted cookies. Hardness of cookies significantly decreased with 100% level of fat replacement, but 75% fat replacement was similar to the control. Brittleness was significantly reduced in both reduced-fat levels. The authors concluded that 75% fat reduction produced cookies most similar to the control in spread, color, hardness, and brittleness.

Sugar Replacers in Cookies

Incorporation of sugar replacers in bakery products has been studied. To investigate the stability of the sweetening power of Acesulfame-K (Ace-K), the sweetener was subjected to elevated temperatures and prolonged baking times in several bakery products including cookies (Klug and others 1992). Using high performance liquid chromatography, Ace-K recovery rates of 99.4, 100.6, 100.6, and

99.1 % were found for Ace-K-sweetened cookies, cakes, cheesecake, and apple pies, respectively. The high recovery rates indicated that Ace-K does not decompose under intense baking conditions.

Polydextrose and several sugar alcohols (isomalt, lactitol monohydrate, maltitol, and sorbitol) have been successfully used to replace sugar in cookies (Olinger and Velasco 1996). Cookie spread, texture, sensory quality, and shelf-life were evaluated. Lactitol, maltitol, and sorbitol cookies had greater spreads than the control; isomalt had less spread; polydextrose had minimal spread. The test cookies, except those containing polydextrose, were notably softer than the sucrose control as per hardness evaluation on a texture analyzer. The polydextrose treatment resulted in a harder cookie.

Sensorily, lactitol performed equal to the control in external appearance, maltitol was darker, and sorbitol had a sticky surface. A light-spotted, nonuniform surface and reduced spread were seen in the polydextrose cookie. Panelists rated lactitol as most similar to control in internal characteristics and maltitol, isomalt, and sorbitol were considered soft or very soft; polydextrose was rated as dense and hard. In the sugar alcohol formulas, it was found that high-intensity sweeteners were necessary to achieve an equi-sweetness to sucrose-sweetened control cookies (Olinger and Velasco 1996),

Cookie Texture

Many crisp and crunchy bakery products, including cookies, pie crusts, ready-to-eat breakfast cereals, cereal bar products and snack foods, can be described as having a friable texture. This friable nature gives the product little or no elasticity and the product will break apart into numerous irregular particles during mastication (Matz 1962). Cookie texture is not limited to this crisp, crumbly, or flaky texture because many products are light, soft or chewy.

Ingredient variation can affect cookie texture. Moisture content is key to what determines the product's dominant texture. Moisture contents of 10% or greater are less friable and 5% or less are more crisp (Matz 1962). Type and amount of sugar can also influence the overall chewiness or crunchiness of the sample. Gaines and others (1992b) found that aged shortening, which can "weep" oil from the more crystalline material, can increase spread, reduce thickness, and produce softer, less crisp wire-cut cookies ($p < 0.05$). Emulsifiers, such as sodium lauryl sulfate, have been shown to reduce hardness (Swanson and others 1999). Lastly, flour quality is critical to texture of baked goods. Gaines and others (1992b) found that as protein content increased 3.1%, probe resistance increased 5 N.

Because cookie texture impacts product quality, understanding how to measure textural attributes is important. Research on flour quality and for product development depends on proper assessment of cookie textural attributes. Both sensory and instrumental evaluation can be used for cookie textural assessment.

Sensory Evaluation of Cookie Texture

Texture of a food is considered highly important to sensory acceptability along with taste and appearance and has been noted to be important to foods that are considered crunchy, crisp, or more bland in flavor (Bourne 1982). Many definitions of texture have been proposed, but food scientists have found one definition cannot encompass every food application. Szczesniak (1963) defined texture as "the composite of the structural elements of food and the manner in which it registers with the physiological senses." Bourne (1982) described "food texture as a group of physical properties which are sensed by the feeling of touch, not related to taste or odor, and which can be measured objectively as functions of mass, distance, and time."

Sensory methodology can be employed to differentiate among, describe, or hedonically score products. In order to describe a cookie's textural properties and possibly correlate perceived intensities with instrumental analysis of texture, descriptive techniques are commonly employed. Texture Profile Analysis (TPA®) emphasizes the structural aspects of the food and how they are perceived sensorily. Comparisons of the food with standard reference products are made by trained panelists. Standard rating scales exist for mechanical parameters of hardness, fracturability, chewiness, gumminess, adhesiveness, and viscosity (Szczesniak and others 1963). Muñoz (1986) has also provided similar scales for the additional parameters of springiness, cohesiveness, cohesiveness of mass, self-adhesiveness, manual adhesiveness, and adhesiveness to palate, lips, and teeth.

The mechanical attributes of hardness, fracturability, gumminess, and chewiness are applicable to cookies. For sensory evaluation purposes hardness is defined as the "force required to compress a substance between the molar teeth" (Szczesniak 1963). Fracturability is the "force with which the sample crumbles, cracks, or shatters" (Szczesniak 1963). Many flour-based bakery products, including cookies, may have some degree of chewiness and gumminess. The length of time needed to chew a food at a constant rate of force in order to prepare the sample for swallowing is known as chewiness. Gumminess is a denseness of the samples which persists throughout the chewing process. The amount of energy needed to disintegrate the gummy sample for swallow is measured as gumminess (Bourne 1982).

Cookies can also exhibit "chemical characteristics," which are attributable to the moistness, dryness, oiliness, and fattiness of a product and are addressed with moisture, fat, wetness, and moisture absorption scales (Szczesniak and others 1963; Muñoz 1986). Scales for geometrical parameters such as denseness and roughness have also been developed (Muñoz 1986). Mechanical, chemical, and geometrical scales can be modified to the food being assessed (Bourne 1982).

The TPA® method requires the separation of textural assessment from other important sensory attributes such as color, aroma and taste; therefore Quantitative Descriptive Analysis® (QDA®) may be useful in descriptive analysis. This method requires a consensus approach for attribute language development and encompasses evaluation of all the sensory properties of the product (Stone and Sidel 1993). Armbrister and Setser (1994) utilized QDA® to study reduced-fat chocolate chip cookies. A 5-member trained sensory panel selected and defined terminology for textural, appearance, and flavor attributes. Reference products and assigned values were also selected by the panel.

Instrumental Evaluation of Cookie Texture

The multi-parameter nature of cookie texture indicates that several instrumental techniques may be needed to fully assess the sample. The instrumental method that best correlates with sensory evaluation is ideal. Finding ideal instrumental methods may be difficult because the "variation in compression rates in the mouth, non-linearity of jaw movements, and the increasing rate of chews as mastication continues" contribute to the complexity of mastication (Faridi 1994). When instrumental methods are correlated with sensory evaluation, correlation coefficients of 0.9-1.0 are considered to indicate that the instrumental method chosen can be a reliable predictor of sensory texture (Bourne 1982). Additionally, sources of variation, which include testing conditions and variability within the product, must be controlled (Gaines 1991b). Variation within a cookie is usually greater than the variation among cookies (Gaines 1991b). To reduce this variability, increased sample size and multiple readings from each sample unit are required.

Probing, compression, bending, and snapping are the usual instrumental techniques employed in cookie and cracker texture assessment. The 3-point break and probing methods are considered most applicable for cookies and crackers (Gaines 1991b). Brown and others (1998) found that compression and probe tests gave greater discrimination between samples than those from a 3-point bend test. Muellenet and Gross (1999) found that sensory perception of hardness, fracturability, and cohesiveness could be predicted using an instrumental test featuring a single compression cycle.

Hardness and fracturability can be evaluated with the “3-point break”, “triple beam snap”, or “snap test” with the use of a Universal Testing Machine (UTM). The cookie rests on two supporting beams and a third moves down to “snap” the cookie between and parallel to the other two beams (Bourne 1982). This method is ideal for foods in the shape of a bar or sheet and of uniform size and shape (Bourne 1982). The thickness of the sample is critical because snapping force is proportional to the square of the thickness or cube of the diameter.

Cookie hardness can also be measured with probing, which is a measure of the response of the cookie to compression and shear (Gaines 1991b). Generally, probing detects more variation within the cookies than among cookies, but more holes probed in a cookie decreases intra-cookie variance. Probes greater than 2-mm diameter, but not large enough to break the cookie apart, are recommended along with a deformation rate of 300-mm/min. Probing has been shown to significantly correlate with sensory evaluation of sugar-snap and wire-cut cookie hardness (Gaines and others 1992a). Gaines and others (1992b) also found probing with a 300-mm/min cross-speed and a 4.5-mm diameter probe to be sensitive enough to detect hardness differences attributable to ingredient variation, wheat cultivars, flour protein content, and crop year.

Cookie texture is only 1 parameter that can provide a picture of flour baking quality. Measurements such as diameter, thickness, and spread factor have also been correlated with flour quality attributes, such as flour protein content. The milling industry relies on research that can help determine critical predictors of soft wheat flour quality. When new formulations include replacers for fat and sugar, seeking further understanding of ingredient functionality, including that of the role of flour, must be the goal to ensure continued production of high-quality bakery products.

Chapter III

EVALUATION OF COOKIE SPREAD AND HARDNESS OF A MICRO WIRE-CUT COOKIE FORMULATED AT 4 FLOUR PROTEIN LEVELS, 3 FAT REPLACERS AT 4 LEVELS, AND 3 SUGAR REPLACERS AT 3 LEVELS

Abstract

The effects of 4 flours at 5.8, 7.5, 8.8, and 10.4% protein levels, 3 fat replacers (Betatrim, Stardri, and Simplesse) at 0, 35, 55, and 75% fat reduction, and 3 sugar replacers (Sucralose, Isomalt, and Maltitol) at 0, 45, and 65% sugar reduction on wire-cut cookie quality were studied in a randomized balanced incomplete block design. For each treatment (n=280), cookie spread (width/thickness) and hardness were measured.

Cookie spread was affected by flour protein X fat replacer X fat level ($p = 0.0102$) and fat replacer X fat level X sugar replacer X sugar level ($p = 0.0244$). Full-fat and 35 and 55% reduced-fat cookies became smaller when flour protein increased as did flour hydration properties. Betatrim at 55 and 75% produced smaller cookies than each respective full-fat/flour counterpart. Stardri cookies at 55 and 75% were larger than the full-fat cookies. For all fat replacers, 75% reduced-fat cookies with the 5.8% protein flour were larger than the 35% reduced-fat cookies with the 10.4% protein flour. Fat replacers with Isomalt or Maltitol at any level, increased cookie spread compared to the full-fat/full-sugar cookie. When combined with Isomalt or Maltitol at any level, Stardri at all levels produced larger cookies than did the full-fat or other fat replacer treatments.

Full-fat cookies and cookies at 35% fat reduction became softer as flour protein increased from 7.5 to 10.4% ($p = 0.0053$). Flour protein level did not affect Betatrim cookie hardness at 55 and 75% fat reduction levels. For all flours and within each fat

level, Stardri cookies were significantly harder than the other reduced-fat cookies.

Bakers must recognize that low-protein flour will produce reduced-fat cookies with larger spreads and desirable textures. Bakers can also use Isomalt or Maltitol for sugar replacement in reduced-fat cookies; ideal fat/sugar replacer combinations can be selected to produce cookies with optimal spread.

Introduction

Optimization of reduced-calorie bakery products is critical for success in the marketplace. Even with the numerous fat replacers and sugar replacers available to industry, formulating reduced-fat and/or reduced-sugar products is a challenge. Cookies, one popular commercial bakery product, are often available in low-fat and low-sugar varieties. Flour, the primary structural ingredient in a cookie system, complexes with fat, sugar, and water to form a workable dough. When fat and sugar are reduced and new replacers added, the normal physicochemical changes that occur during the baking process are ultimately altered. Under normal baking conditions, flour quality is critical. Therefore, investigation of the role of flour quality in fat- and sugar-reduced baking formulations is needed.

Soft wheat flour quality is important to baking performance. A wire-cut cookie formula has been used to investigate the importance of flour attributes, such as protein content, ash, pH, alkaline water retention capacity (AWRC), and mixing qualities to baking quality. Cookie spread (width/thickness) has been shown to be inversely correlated with protein content (Labuschagne and others 1997; Gaines 1985). Flour ash and AWRC values, when combined with protein value, can be predictors of cookie diameter (Gaines 1990). Industry considers large diameters and/or spread values superior (Kaldy and Rubenthaler 1987).

Flour protein content has also been correlated with cookie texture. Harder cookies are produced with high protein flours; if protein is too low, cookies produced are too dense (Posner and Hibbs 1997). Gaines and others (1992a) found that cookies produced with flours with protein contents of 6.9 and 8.1% were similar in hardness but significantly softer than cookies made with 10% protein flour ($p = 0.05$).

Generally, cookie flour in the United States is 7.5-8.5% protein and 0.38-0.42% ash and has a pH of 5.8-6.0 (Pyler 1988). When stronger flours (higher protein) are used, cookie formulations must be high in fat and sugar to retain tenderness (Pyler 1988). Therefore, when sugar and fat are intentionally reduced in a cookie formulation, a flour of low protein content may produce better cookies and greater fat and/or sugar reduction may be achieved. In order to study the effects of flour protein content, fat replacer, and sugar replacer, on cookie quality the objectives for Part 1 of a 2-part study were:

1. To characterize 4 flours, designed to progressively increase in protein content in order to examine how flour protein and other attributes influence quality of an AACC standardized wire-cut cookie.

2. To investigate the effects of flour protein content, fat replacement, and sugar replacement and the interactions among these variables on cookie spread.

3. To utilize an instrumental measurement of cookie hardness in order to investigate if flour protein content, fat replacement, and sugar replacement and the interactions among these variables will affect cookie hardness.

4. Based on cookie spread and hardness results, to select optimal reduced-calorie cookie formulas for a sensory evaluation study in Part 2.

Materials and Methods

Experimental Design

A randomized balanced incomplete block was used for the statistical design. The Micro Wire-Cut Cookie Formula (AACC Method 10-54) was used with variation in fat replacer, sugar replacer, and flour protein level (Table III-1). The design consisted of 3 fat replacers at 4 levels, 3 sugar replacers at 3 levels, and 4 flour protein levels, to give 280 treatment combinations. One replication was blocked over 20 d with 14 observations per day, then repeated for the second replication. Baked cookies were evaluated for cookie spread and instrumental hardness 2-d post-bake.

Experimental Material

Flours

To represent low-protein and high-protein levels, 2 flours were obtained from a commercial miller (White Lily Foods, Inc., Knoxville, TN). Both flours were obtained from the same production line, therefore produced from the same wheat composite. The low- and high-protein flours were extracted from the 1st sifter and 4th break, respectively. Two additional flours were prepared by blending 66.7% of the low-protein flour with 33.3% of the high-protein flour and 33.3% of the low-protein flour with 66.7% of the high-protein flour. Each of the 4 flours (6.8 kg) was mixed for 7 min on Speed 1 in a 20-L Hobart® planetary mixer (Model A-200, Hobart, Troy, OH) equipped

Table III-1–Basic micro[a] wire-cut cookie formula

Ingredient	Weight (g)	Flour weight basis (%)
Flour, 13% moisture basis[b]	40.0	100.0
Fat/fat replacer system[c]	16.0	40.0
Sugar/sugar replacer system[d]	17.6	44.0
High-fructose corn syrup, 42%[e]	0.6	1.5
Salt[f]	0.5	1.3
Nonfat dry milk[g]	0.4	1.0
Sodium bicarbonate[h]	0.4	1.0
Ammonium bicarbonate[i]	0.2	0.5
Water, deionized	8.8	22.0

[a] Formulation amounts for 2 cookies; adapted from method 10-54 (AACC 2000).
[b] Final weight for each flour with water was adjusted to a 13% moisture basis to give equivalent of 40 g; White Lily Foods Co., Knoxville, TN.
[c] Components shown in Table III-2.
[d] Components shown in Table III-3.
[e] Cargill Inc., Dayton, OH.
[f] Morton® Salt, Chicago, IL.
[g] Armour Food Ingredients, Springfield, KY.
[h] Arm & Hammer®, Church & Dwight Co., Inc., Princeton, NJ.
[i] Vitusa Products Inc., Berkeley Heights, NJ.

Table III-2–Fat/fat replacer system for micro[a] wire-cut cookie formula

Fat reduction(%) Fat replacer	Ingredients (g)					
	HVO[b]	Fat replacer	Water	Mono- and diglycerides[c]	Lecithin[d]	Polydextrose[e]
Full fat (0)	16.00	-	-	-	-	-
Reduced fat (35)						
Betatrim™[f]	9.60	0.95	2.85	0.80	0.30	1.50
Stardri[g]	9.60	1.20	2.60	0.80	0.30	1.50
Simplesse[h]	9.60	1.30	2.50	0.80	0.30	1.50
Intermediate fat (55)						
Betatrim™	6.60	1.50	4.60	0.80	0.30	2.40
Stardri	6.60	1.90	4.20	0.80	0.30	2.40
Simplesse	6.60	2.00	4.10	0.80	0.30	2.40
Low fat (75)						
Betatrim™	3.20	2.00	5.40	0.80	0.30	3.24
Stardri	3.20	2.50	5.60	0.80	0.30	3.24
Simplesse	3.20	2.70	5.70	0.80	0.30	3.24

[a] Formulation amounts for 2 cookies; adapted from method 10-54 (AACC 2000).
[b] Hydrogenated vegetable oil, CreamTex® Shortening (Ventura Foods, Inc., City of Industry, CA.).
[c] Mono-/diglycerides enriched with BHT and citric acid (Dur Lo®, Loders Croklaan, Glen Ellyn, IL).
[d] Phosphatidylcholine-enriched soybean lecithin (Lecimulthin 130®, Lucas Meyers, Decatur, IL).
[e] StaLite III®, A.E. Staley, Decatur, IL.
[f] Hydrolyzed oat flour, Rhodia Food Ingredients, Cranbury, NJ.
[g] Maltodextrin, A.E. Staley, Decatur, IL.
[h] Microparticulated whey protein, Kelco Biopolymers, San Diego, CA.

Table III-3–Sugar/sugar replacer system for micro[a] wire-cut cookie formula

	Ingredients (g)				
Sugar reduction (%) Sugar replacer	Sucrose[b]	BG-sucrose[c]	Sugar replacer	Ace-K[d]	Poly-dextrose[e]
Full sugar (0)	12.80	4.00	-	-	-
Reduced sugar (45)					
Isomalt[f]	6.50	2.70	5.70	0.04	1.90
Maltitol[g]	6.50	2.70	5.70	0.04	1.90
Sucralose[h]	6.50	2.70	0.68	-	1.90
Reduced sugar (65)					
Isomalt	3.20	2.70	8.10	0.05	2.80
Maltitol	3.20	2.70	8.10	0.05	2.80
Sucralose	3.20	2.70	0.96	-	2.80

[a] Formulation amounts for 2 cookies; adapted from method 10-54 (AACC 2000).
[b] Fine-granulated sucrose (Kroger's, Cincinnati, OH).
[c] Brownulated granulated sucrose (Domino Specialty Ingredients, Baltimore, MD).
[d] Sunette® Brand, Nutrinova, Somerset, NJ.
[e] StaLite III®, A.E. Staley, Decatur, IL.
[f] Polyol (isomaltulose); Palatinit-Subungsmittel Gmblt Mannheim, W.Germany.
[g] Polyol (hydrogenated maltose); Maltisorb®P200, Roquette America, Inc., Keokuk, IA.
[h] Selectively chlorinated sucrose; Splenda®, McNeil Specialties, Inc., New Brunswick, NJ.

with a flat beater attachment . After mixing, each flour was transferred to 5, 2-L air-tight Mason jars (Ball Corp., Munice IN) and stored at 25° C for the length of the study.

Reduced-Fat and Reduced-Sugar Cookie Formulas

Based on preliminary work, 3 fat replacers were chosen to represent fat replacers commonly used in industry. These included a maltodextrin, a hydrolyzed oat flour, and a microparticulated protein fat mimetic. Full fat (100% shortening) and 3 fat replacers at 35, 55, and 75% fat reduction levels were used (Table III-2). The 35 and 75% levels were designed to approximate the legal definitions of "reduced fat" and "low fat". Reduced fat cookies must provide at least 25% less fat than the full-fat product; low-fat cookies have no more than 3 g fat per serving (FDA 2000). An intermediate fat reduction level was achieved with the 55% level. Polydextrose, lecithin, and a mono- and diglyceride emulsifier were added to improve texture, mouthfeel, and dough handling as suggested in previous studies (Hodgson and others 1993) and concluded during preliminary work . Additional water was added for fat replacer hydration, which also achieved caloric reduction.

Sugar replacement was achieved with 2 polyols, Isomalt and Maltitol. Sucralose, a selectively chlorinated sucrose compound, was the third sugar replacer used. Based on preliminary work, polydextrose was added to all reduced sugar cookies at 10% of the sugar replacer level. The 2 polyol treatments required the addition of a high intensity sweetener, acesulfame-K (Ace-K). Ace-K concentration that was most similar in sweetness to the full-sugar was determined in preliminary work. As presented in Table III-3, sugar replacers were used at 0, 45, and 65% reduction levels to establish a control (full-sugar) and low and high levels of sugar reduction, respectively. Cookies formulated with the highest fat (75%) and sugar (65%) replacement levels resulted in an estimated 36% caloric reduction, which meets the legal definition for "reduced calorie" (FDA 2000).

Experimental Procedures

Flour Characterization

Protein. Percentage protein of each flour was determined in triplicate with the improved Kjeldahl method (AOAC 1995). Weighed flour samples (~2 g) were transferred to 250-mL Kjeldahl flasks (Tecator, Inc., Herndon, VA) and 2 Kjeltabs (89.7% K_2SO_4, 10.3% $CuSO_4$; Thompson and Capper, LTD, Chesire, England) plus 15 mL of concentrated sulfuric acid (36 N) were added. Samples were digested in a 420°C digestion heating unit (2020 Digestor, Tecator, Inc., Herndon, VA) for 90 min. Samples were cooled for distillation. In Erlenmeyer receiver flasks containing 25-mL Kjel-Sorb reagent (4% boric acid), 100-150 mL were collected through distillation of the samples with alkali (40% NaOH solution) and water reagents (Kjeltec System 1026 Distilling Unit set at alkali-2, delay 0.2, steam 3.6, Tecator Inc, Herndon, VA). Distilled samples were titrated to a neutral grey endpoint. Grams of nitrogen was determined from milliliters of acid used, and a 5.7 nitrogen conversion factor was used for percentage protein determination (AACC 2000). Percentage protein was adjusted and reported on a 14% moisture basis.

Moisture. Moisture contents for the 4 flours were determined according to the Modified Vacuum-Oven Method 44-40 (AACC 2000). In triplicate, weighed flour samples (~2 g) were transferred to pre-weighed aluminum pans, dried overnight in a vacuum oven

(GCA Corp., Chicago, IL, 80 C, 20-25 psi) and weighed. On a daily basis, this method was used to determine moisture content of the 4 flours in order to adjust the flour to a 14% moisture basis according to the Baking Quality Wire-Cut Cookie Micro Method 10-54 (AACC 2000).

pH. Method 02-52 (AACC 2000) was used to determine flour pH in triplicate. Flour slurries were prepared with 10 g of flour and 100-mL deionized water, suspended for 15 min with a magnetic stirrer, and allowed to set for 10 min. Decanted supernatant liquid was measured with a pH meter (Orion Model 230A, Boston, MA). Average pH values were reported for each flour.

Ash. Ash was determined according to Method 08-01 (AACC 2000). Flour samples (~3 g) were weighed into pre-weighed porcelain crucibles. Samples were placed in a cold muffle furnace oven and brought to 550° C for a minimum of 10 hr. The oven was cooled to room temperature and the crucibles transferred to a dessicator, cooled, and weighed to the nearest 0.01g. Percentage ash was calculated and adjusted to a 14% moisture basis.

AWRC. Alkaline water retention capacity (AWRC) was determined on each flour according to Method 56-10 (AACC 2000). Flour samples (0.95-1.0 g) of known moisture content were placed in pre-weighed, 15-mL polypropylene centrifuge tubes with stoppers and 5 mL of a 0.1N sodium bicarbonate solution were added. By hand, tubes were shaken vigorously to suspend flour and held for 20 min, with shaking every 5 min. Samples were centrifuged (Sorvall® RC5B Plus, Kendro Laboratory Products, Newton, CT) for 15 min at 1000 x g. After decanting liquid for 10 min, the remaining gels plus tube and stopper were weighed. Percentage AWRC was calculated to determine amount of alkaline water held by flour (14% moisture basis).

Mixograph analysis. Mixing characteristics of the 4 flours were determined according to method 54-40A (AACC 2000). With a mixograph (National Manufacturing Co., Lincoln NE), flour of a known moisture content was mixed in a "35-g" flanged mixing bowl for 10 min. According to the AACC method, flour weight and a correction factor for water amount was based on amounts needed to adjust flour to a 14% moisture basis. Optimal dough development was estimated by adjusting water content until an optimum mixograph curve resulted, which determines the optimal absorption level of the flour. Once this optimal absorption level was determined, triplicate mixograms for each flour were run. Mixograms were evaluated to obtain time to maximum height (min), maximum peak height (cm), angle of development, and angle of breakdown. Values were averaged for each flour (AACC 2000, Pyler 1988). To illustrate these values, a standard mixogram is presented in Figure III-1.

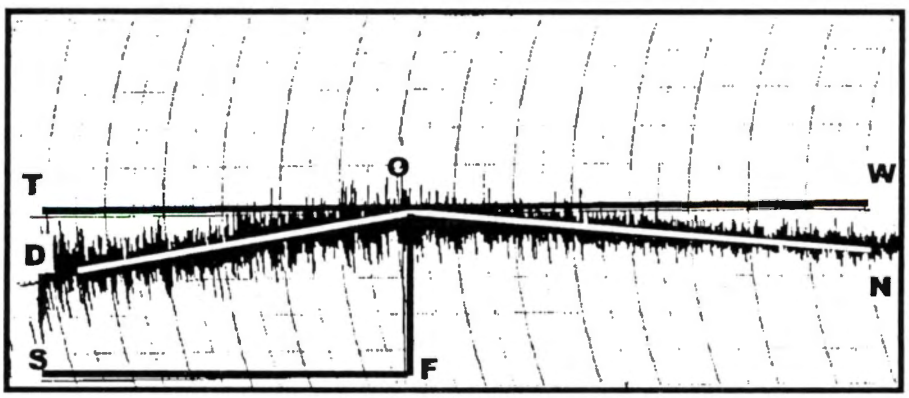

Figure III-1. Typical mixogram of the 10.4% protein flour (S-F = development time, DOT = development angle, F-O = peak height, WON = breakdown angle).

Mixing and Baking Procedures

The Micro Wire-Cut Cookie Method 10-54 (AACC 2000) was used for the control cookie formula and adapted for reduced-fat and -sugar formulations (Tables III-1,-2, and -3). Modifications of equipment and baking procedures were made. A National mixograph (Lincoln, NE) was used to mix the cookie doughs. Except for the flour, dry ingredients were pre-weighed and stored in 30-mL plastic disposable containers with lids (Solo Cup Co., Urbana, IL). One treatment at a time, dry ingredients minus flour were combined and stirred for 30 sec in a "35-g" mixograph bowl, shortening was added, and the mixture was creamed for 3 min, scraping every min. In a 50-mL beaker, high fructose corn syrup (HFCS) and ammonium bicarbonate was swirled together with the calculated amount of water (formula water + additional water for fat replacement as stated in Table III-2). The liquid mixture was added to the creamed mass in the mixograph bowl and mixed for 1 min, scraping after 30 sec. Flour was added to the moistened creamed mass and mixed for 30 sec, scraping every 10 sec.

Dough was removed from the bowl, divided into 2, 37-g portions, and placed on aluminum cookie sheets lined with parchment paper. The cookie sheets were placed between two stainless steel rolling guides and a gauze-covered rolling pin was used to roll the cookie doughs to a 7-mm thickness. The gauze covering prevented dough sticking to the rolling pin. The doughs were rolled once to simulate manufacture of a wire-cut cookie. Cookie doughs were cut to 60-mm diameter with a stainless steel cutter, trimmed of excess dough, and baked in a 205° C rotary oven (National Manufacturing Co., Lincoln, NE) for 7.5 min. Oven shelves were lined with 12.7-mm thick unglazed ceramic quarry tiles (Metropolitan Ceramics, Canton, OH) for improved heat distribution. While still on the cookie sheets, cookies were cooled on wire racks for 5 min. Cookies were removed from the cookie sheets (remained on parchment paper), cooled for an additional 60 min, and then stored in marked resealable sandwich bags (Kroger Co., Cincinnati, OH) for 2 d.

Product Evaluation

Cookie spread. Cookie width, thickness, and spread values were determined. A digital vernier caliper (Mitutoyo Corp., Kawasaki, Japan) was used to obtain 4 diameter measurements (to the nearest ½ mm) of the 2 cookies for each treatment. The 2 cookies were aligned edge to edge, measured, and rotated 1 quarter turn, and measured again. Cookies were rotated and measured 2 more times. The average of the 4 values was calculated as final width. For 2 separate height readings, 2 cookies were stacked and restacked and measured with the vernier caliper (to the nearest ½ mm) at center of top cookie; the average was reported. Cookie spread, calculated as the ratio of diameter to width, was determined.

Cookie hardness. Two days post-bake, a TA.TXT2 Texture Analyzer (Texture Technologies, Scarsdale, NY), equipped with a 3-mm diameter flat-ended probe, was used to evaluate cookie hardness. Each cookie was probed 7 times, once in the center, and 6 times in a hexagonal pattern around the initial center probe. The probing guide used and instrument settings are seen in Appendix A. The outer 1-cm edge was avoided for the 6 outer probes, because this portion of the cookie could result in unusually high hardness values. Maximum peak force was recorded for each probe, and the 7 probe values were averaged for mean peak force.

Statistical Analysis

PROC GLM (SAS Institute, Inc 2000) was used to analyze differences in flour protein, ash, and moisture contents, AWRC values, pH, and dough development characteristics (Appendix B). All values for cookie width, thickness, spread, and mean peak force (hardness), were tested for equal variance (PROC MEANS, SAS Institute, Inc 2000) and PROC UNIVARIATE (SAS Institute, Inc 2000) was used to test for normality of the data. Cookie spread and hardness were analyzed for differences among the main effects and interactions of flour protein, fat replacer and level, sugar replacer and level (PROC MIXED, SAS Institute, Inc 2000)(Appendix B). Treatments were blocked on day and one replication conducted; baking day and replication were random factors in the model. Least-squares means were generated and the PDIFF function was used to test for significant differences (SAS Institute, Inc 2000).

Results and Discussion

A randomized incomplete block design was used to examine the effects of 4 flour protein levels, 3 fat replacers at 4 levels, and 3 sugar replacers at 3 levels on cookie spread and texture. Significant interactions between flour protein X fat replacer X fat level (FPRO X FATR X FATL) and fat replacer X fat level X sugar replacer X sugar level (FATR X FATL X SUGR X SUGL) were found for cookie spread and cookie hardness (Appendix C). However, spread and texture measurements for the Sucralose sugar cookies were significantly smaller than for the other fat and sugar cookie variations. Spread values for Sucralose cookies at both 45 and 65% sugar reduction ranged from 2.9 to 4.8 which were considerably below accepted standards of 7.5 to 7.9

(Anonymous 2001). These cookie spread differences among the cookies sweetened with full sugar and the 3 sugar replacers at a 65% sugar reduction are represented in Figure III-2.

Textures of Sucralose cookies also indicated that this replacement system was not ideal. FATR X FATL X SUGR X SUGL was significant for cookie hardness ($p < 0.0001$). Regardless of the fat treatment, Sucralose cookies required significantly less force to penetrate. Cookie hardness ranged from 296 to 758 g for Sucralose containing cookies; non-Sucralose cookies ranged from 614 to 1774 g in hardness but only 3 of the possible 50 fat and sugar treatment combinations were less than 700 g.

When peak profiles of the 4 sugar treatments produced by one-probe measurements on the texture analyzer are compared, differences in the cookie matrices are suggested (Figure III-3). In the Sucralose cookie, the maximum peak force occurred later compared to the other 3 cookies, indicating this was the force needed to exit the bottom crust of the cookie. This maximum peak force, or hardness, was also less than the other 3 sugar variations. The valley between the 2 peaks indicates the Sucralose cookie either possesses a soft cake-like matrix composed of large voids or possibly a chewier texture is present with little or no fracturability. Bourne (1982) indicates that fracturability of a food product is a measure of the horizontal force with which a food moves away from the point where the vertical force is applied and/or the suddenness with which the food breaks.

Matz (1962) explains that in a sugar-snap or shortbread type cookie small pockets of air persist between surrounding layers of dough that become brittle or hard during baking. This layering effect contributes to the fracturability of the product. The multi-peak profiles of the Isomalt cookie and full-sugar cookie suggest this layering and

Figure III-2– Effect of sugar and sugar replacers on wire-cut cookie spread for cookies formulated with full fat and 5.8% protein flour (A = sugar, B = Sucralose, C = Isomalt, D = Maltitol; spool height =1.9 cm).

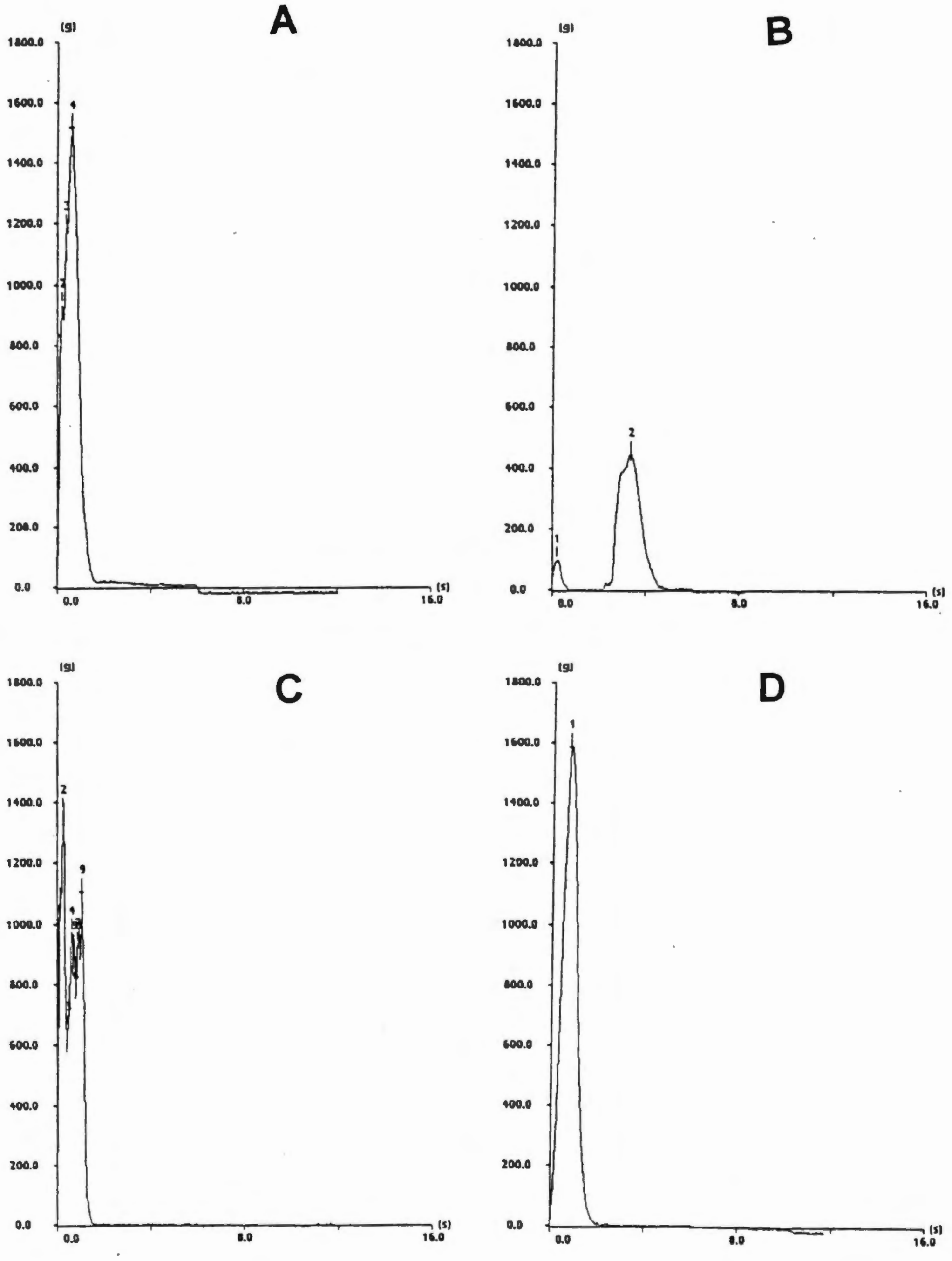

Figure III-3– Profiles of single probe hardness measurements of wire-cut cookies formulated with sugar and 3 sugar replacers, 5.8% protein flour/full-fat (A = sugar, B = Sucralose, C = Isomalt, D = Maltitol).

gas pocket formation were present. Isomalt and full-sugar cookies would be more likely to possess the traditional "snap characteristics" associated with this type of cookie product. The Maltitol cookie possessed one peak which indicated that the cookie shattered or broke apart on initial penetration by the probe and the force needed to penetrate the cookie was greater than that needed for the Sucralose cookie. Additional research in needed to investigate if the probing technique used in this study is an indicator of fracturability and/or other textural properties of cookies.

Overall, these findings indicate that Sucralose did not successfully replace the bulking function of sucrose in these test formulations. Sucralose, which is marketed as Splenda®, is suggested on the manufacturer's label to function on a 1:1 volume replacement basis for sucrose. This sweetener is blended with a maltodextrin, which serves as a carrier and provides the volume. Preliminary work of the reduced-sugar formulas was based on production of 8 cookies using a macro-wire cut formulation. This formula was re-scaled to make 2 cookies and this reduction in quantity of cookies produced may have resulted in the diminished performance. Sucralose treatments were removed from the data set because the low spreads and hardness values were considered as outliers (Saxton 2001). The new experimental design of 4 flour protein levels, 3 fat replacers at 4 levels, and 2 sugar replacers at 3 levels was used for further analysis.

Flour Characterization

Protein contents of the 4 flours were 5.8, 7.5, 8.8, and 10.4% and the flours are characterized in Table III-4. All flours were taken from the same production line to control variation in the flours attributable to different wheat sources. Blending proportions appeared to have successfully produced the 2 intermediate protein levels. The additional flour tests provided some indication of potential flour performance in the cookie formulas.

Percentage ash reflects bran and germ contents. As expected, ash content increased as the proportion of the 4th break flour increased. Ash content was considerably lower for the 1st break flour which is predominantly endosperm, and this flour was significantly lower in ash than the 8.8 and 10.4% protein flours. Flour pH did not vary much among the flours except a slight increase was seen as protein content increased. The 2 lower protein flours were significantly lower in pH compared to the 2 higher protein flours. Cookie flours are often chlorinated to a low pH of 4.8 in order to

Table III-4– Characteristics of flours

		Flour protein level (%)[a]							
Attribute	p value	5.8		7.5		8.8		10.3	
Ash (%)[b]	0.0115	0.22	a	0.37	ab	0.49	bc	0.62	c
AWRC [b]	0.0006	64	a	70	b	74	c	77	c
pH	0.0073	6.0	a	6.1	a	6.2	b	6.2	b
Moisture (%)[c]	0.3300	13.0		13.4		13.3		13.2	
Mixograph values [d]									
Optimal absorption (%)[e]		45.1		47.6		58		60.4	
Maximum peak height (cm)	0.0032	3.5	a	4.3	b	4.4	b	4.7	b
Dough development time (min)	0.0002	3.7	a	3.9	a	5.9	b	6.4	b
Angle of development (°)	0.0028	5.7	a	3.7	b	5.0	ab	8.3	c
Angle of breakdown (°)	0.0044	1.7	a	2.0	ab	3.0	bc	4.0	c

[a] Adjusted to a 14% moisture basis; all flours were statistically different in protein content ($p < 0.0001$).
[b] Adjusted to a 14% moisture basis.
[c] Average of daily moisture values over length of study (40 d).
[d] As measured with a Mixograph (National Manufacturing, Lincoln, NE).
[e] Optimal water level determined according to Method 54-40A (AACC 2000).

control (decrease) cookie spread (Gaines and others 1988); therefore the high pH values of the flours would not be expected to impact cookie spread significantly. Swanson and others (1999) found that cookie spreads were reduced with Oatrim fat replacement even though cookie doughs became more alkaline. This suggests that fat replacement may override minor changes in flour or dough pH. Further study of flour and dough pH may be warranted.

Differences in the water retentive properties among the 4 flours existed. Moisture was measured on a daily basis, but mean estimates indicated that flour significantly decreased in moisture content as protein content increased; however the water retention capacities (AWRC) significantly increased as flour protein increased to 8.8%. Apparently the proportion of the 4th break flour significantly increased water retention capacity of the 8.8% protein flour. The flours with the lower AWRC values would theoretically absorb less water and permit complete hydration of the sugar component. When sucrose is thoroughly dissolved, cookie dough is more fluid and spreads more during baking (Yamazaki 1955).

The increased AWRC values in the higher protein flours may also be a result of starch damage that can occur as the endosperm is crushed and fractured during separation from the germ and bran (Posner and Hibbs 1997). Increased grinding and pressure of the 4th break may result in this starch damage. A 200% increase in absorption occurs when the starch is damaged (Manley 1991). Therefore, high protein and possible damaged starch would contribute to the increased absorptive properties of the 8.8 and 10.4% protein flours. Further research would be needed to confirm this.

Dough development characteristics are also presented in Table III-4. Mixogram peak height has been shown to be directly proportional to flour protein content;

however the 3 higher protein flours were not different in peak height. Therefore, the mixogram may not have been sensitive to the minute differences in protein content of these flours although protein contents were significantly different.

Dough development times for the 2 lower protein flours were similar but were significantly shorter than the 2 higher protein flours. Time of development is an indication of time needed to hydrate the flour components and develop the protein matrix; normally, low-protein flours take longer to hydrate (Swanson 1986). Because these flours were derived from the same wheat source, hydration time for the 2 higher protein flours may be only reflecting that more time was needed to completely hydrate the increased protein in these flours. Presence of damaged starch from addition of the 4^{th} break flour may also set up a competition for water which would ultimately delay protein hydration.

The higher protein flour had a larger angle of development than the other flours; however long dough development times are generally associated with small development angles (Johnson and others 1943). Unexpectedly, the 7.5% flour had a significantly smaller angle than the 5.8% protein flour. This suggests that the mixograph method may not be the most sensitive technique in ascertaining differences in extremely low-protein flours.

Angle of breakdown is a measure of mixing tolerance. Smaller angles would reflect less breakdown of the gluten matrix that can occur as a result of over mixing (Johnson and others 1943). In this study, angles generally increased as protein content increased, indicating the higher protein flours would be less tolerant to over mixing. However, these results are more likely to be a reflection of increasing protein content versus an indication of the strength (quality) of the flour because flours were from the same wheat blend.

Product Evaluation

As cookie doughs were mixed throughout the study, differences in dough handling were observed. The 5.8% protein flour produced softer doughs that were very easy to roll and cut. When fat replacement was increased to 75% doughs became more sticky. This was especially true for the Betatrim fat replacer which required 3 parts water to 1 part replacer compared to a 2:1 or 2.2:1 water to replacer ratio for Stardri and Simplesse fat-replacement. In a practical application, these low-fat cookie doughs would not be appropriate formulations for commercial wire-cut cookie manufacture. For purposes of this investigation, these formulations were used because alteration of the 75% low-fat formulas would require either less water or additional replacement ingredients. This would increase caloric values and make comparisons between the other levels of fat reduction difficult. For ease in rolling these doughs, the gauze-covered rolling pin was implemented prior to the start of the study. The higher protein flour doughs were generally drier and stiffer. The increased water for fat replacement actually made these cookie doughs more workable.

Cookie Spread

FPRO X FATR X FATL was significant for cookie spread ($p = 0.0102$) (Table III-5). Spread decreased as flour protein increased from 5.8 to 8.8% in the full-fat cookies (Figure III-4). Cookies with the 8.8% and 10.4% protein flours were similar in spread. Large cookie spreads reflect high cookie flour quality (Kaldy and Rubenthaler 1987).

Table III-5–Least-squares mean[ab] estimates of wire-cut cookie spread[c] as a function of flour protein content and fat replacer within fat level

Fat level (%)	Flour protein level (%)[d]							
Fat replacer	5.8		7.5		8.8		10.4	
Full-Fat	8.5	cdef	7.1	klmno	6.2	qrstu	5.8	uvw
Reduced (35)								
Betatrim	8.8	abcd	7.9	ghij	6.9	mnop	6.1	rstuv
Stardri	9.3	a	8.5	def	7.6	ijkl	6.6	opqrs
Simplesse	9.1	ab	7.9	ghij	7.0	mnop	6.3	qrstu
Intermediate (55)								
Betatrim	8.0	fghi	7.1	lmno	6.5	pqrst	6.0	tuv
Stardri	9.0	abc	8.2	efgh	7.4	jklm	6.7	nopq
Simplesse	8.6	bcde	7.3	klmn	6.6	opqr	5.6	vw
Low (75)								
Betatrim	6.7	opq	6.4	pqrst	5.9	uv	5.2	w
Stardri	8.2	efg	8.2	efgh	7.4	jklm	6.6	opqrs
Simplesse	7.7	hijk	7.0	mnop	6.1	stuv	5.8	uv

[a] Least-squares mean estimates of cookie spreads across sugar/sugar replacer system.
[b] Least-squares mean estimates with unlike letters are significantly different ($p = 0.0102$); standard error of the mean = 0.31.
[c] Cookie spread calculated as width (cm) of 2 cookies/height (cm) of 2 cookies per treatment; average of 4 width measurements per cookie and average of 2 height measurements per cookie.
[d] Calculated on a 14% moisture basis.

Figure III-4– Effect of flour protein content on cookie spread for wire-cut cookies formulated with full fat and full sugar (A = 5.8% flour protein, B = 7.5% flour protein, C = 8.8% flour protein, D = 10.4% flour protein; spool height = 1.9 cm).

Cookies with fat replacers were often larger than the full-fat cookies. Comparing the different treatments within 1 flour, this trend is evident. For the 5.8% protein flour, cookie spreads for the Stardri and Simplesse treatments at 35% fat reduction were significantly larger than the full-fat cookie. At the 55% fat reduction level, all cookies were similar in size to the control fat cookie; however, when fat reduction was increased to 75%, cookie spread decreased for Simplesse and Betatrim. Stardri 75% cookie remained similar in size to the full-fat cookie.

For the 2 intermediate protein flours, cookies with fat replacers at 35% fat reduction were larger than the respective full-fat cookies. When fat replacement was increased to 55 and 75% in these 2 flours, Stardri was the only replacer to produce spreads larger than the full-fat counterparts. Cookie spreads for the 10.4% protein flour cookies replaced with Stardri at all fat levels were significantly larger than the full-fat cookie; however all cookie spreads, including full-fat for with this flour, did not meet the industry standard of 7.5-7.9 (Anonymous 2001).

When each fat replacer was examined separately, variation in cookie spread was also seen among the fat levels. With the exception of the 55 and 75% fat reduction with the 5.8% protein flour, Stardri replacement was successful in producing cookies that were larger than any of the full-fat treatments. The increased spreads produced by Stardri suggest that the maltodextrin fat replacer would permit larger variation in flour protein content up to the 8.8%. The higher spreads achieved with Stardri may be attributed to a decreased dough consistency; this increased fluidity increases spread rate during baking (Yamazaki 1955). The hydrophilic nature of the maltodextrin fat replacer was likely sufficient to compete with the extra water that was part of the fat replacement. This water competition likely served to delay gluten formation and starch gelatinization as reported by Nonaka (1997) and Setser and Racette (1992).

Betatrim and Simplesse did not perform as consistently when level of fat reduction increased and when flour protein increased. At 35% fat reduction, Betatrim with the 2 intermediate flours produced cookie spreads larger than full-fat cookies. This was also true for Simplesse, but the 5.8% protein flour with Simplesse produced larger cookies compared to the full-fat. For all 4 flours, Betatrim and Simplesse cookies at 55% fat reduction were not different from the full-fat cookies. When fat reduction was increased to 75%, Betatrim produced smaller cookies than the full-fat cookies in the 2 lowest protein flours; Simplesse 75% cookies were also smaller than the full-fat cookie in the 5.8% protein flour.

These results suggest that Betatrim and Simplesse replacers did not achieve the same increases in cookie spread as Stardri fat replacement when fat reduction and/or flour protein increased. The water holding properties of the fat replacers may account for these differences. Excess water as part of the fat replacement is available for early starch gelatinization and interference with sucrose crystallization. The glass transition temperature of gluten is lowered. These events can decrease spread rate because cookie doughs are more viscous and cookie set-time will also occur sooner, which reduces final cookie spread (Setser and Racette 1992; Miller and others 1997).

One of the objectives of the study was to determine if higher fat reduction was possible when a lower protein flour was used. Based on cookie spread values, Stardri or Simplesse 55% cookies in the low-protein flour were significantly larger than the 35% reduced-fat cookies made with the 3 higher protein flours. When fat replacement was increased to 75%, Stardri and Simplesse fat replacers with the 5.8% protein flour were better than the 8.8 and 10.4% flours. Lower protein flour did not improve spreads for Betatrim replacement. The increased absorptive properties of the higher protein flours may be contributing to the diminished performance of the higher fat contents. When the flour components retain water, sucrose does not to dissolve completely and the thicker doughs do not spread to their fullest potential (Yamazaki 1955). Figure III-5 illustrates cookie spread differences between the higher fat reduction/lower protein flour combination and lower fat reduction/higher protein flour for the 3 fat replacers.

Cookie spread was also affected by FATR X FATL X SUGR X SUGARL ($p = 0.0244$) (Table III-6). Full-fat cookies sweetened with Isomalt and Maltitol at 65% sugar reduction were larger than the full-fat/full-sugar (control) cookie treatment. At 45% sugar reduction, Maltitol cookies were larger; however Isomalt cookies were similar to the control cookie. With the exception of Stardri 35% fat replacement, the full-sugar treatment combined with the various fat replacers did not cause cookie spreads to vary from the control cookie. When fat replacers and sugar replacers were combined, cookie spreads generally improved compared to the control. This was true except for Betatrim fat replacement at 55 or 75% fat reduction in which spreads were similar to the control cookie.

When comparing each fat- and sugar-replacer combination to its respective full-fat treatment, other trends are evident (Table III-6). At 35% fat reduction, most reduced-fat and -sugar cookies were larger than their full-fat/reduced-sugar counterpart. This was true until sugar replacement was increased to 65% with Maltitol in which cookie spreads were equal to the full-fat/Maltitol 65% cookie. At 55% fat reduction, Stardri was the only fat replacer when combined with most of the polyol treatments that resulted in larger cookies than the respective full-fat/polyol cookies.

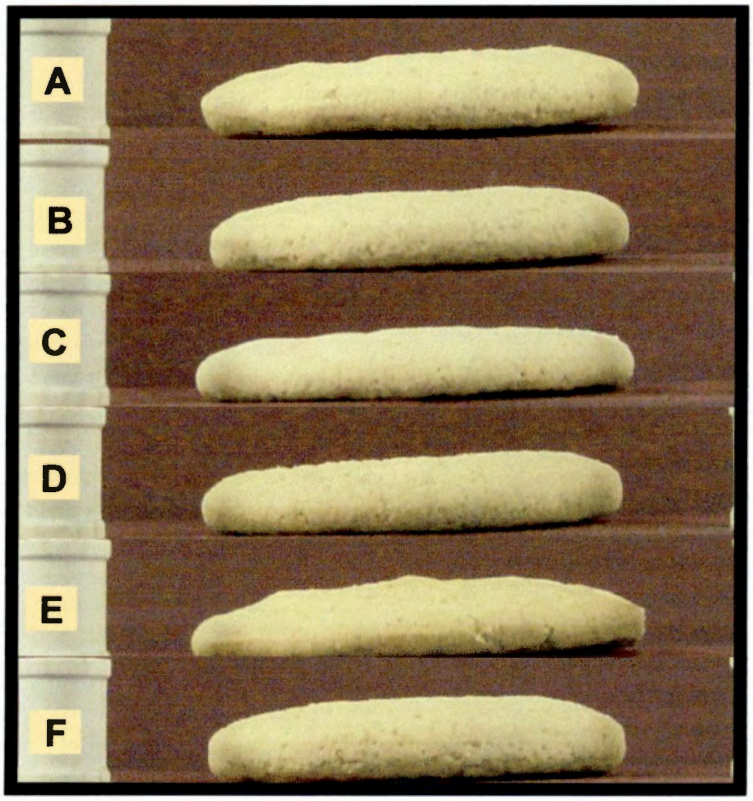

Figure III-5– Effect of flour protein content and fat replacer on cookie spread for wire-cut cookies formulated with full sugar (A = 5.8% flour protein/Betatrim 75%, B = 10.4% flour protein/Betatrim 35%, C = 5.8% flour protein/Stardri 75%, D = 10.4% flour protein/Stardri 35%, E = 5.8% flour protein/ Simplesse 75%, F = 10.4% flour protein/ Simplesse 35%; spool height = 1.9 cm).

Table III-6. Least-squares mean estimates[ab] of wire-cut cookie spread[c] as a function of fat replacer within fat level and sugar replacer within sugar level

Fat reduction (%) Fat replacer	Full sugar		Isomalt (45)		Maltitol (45)		Isomalt (65)		Maltitol (65)	
			Sugar replacer and sugar reduction (%)							
Full fat	6.3	qrstuvw	6.1	tuvw	7.3	ghijklmn	6.8	lmnopqr	8.0	abcd
Reduced (35)										
Betatrim	6.8	lmnopqrs	7.3	ghijklmno	7.9	bcdefg	7.5	defghijk	7.8	cdefgh
Stardri	7.4	efghijkl	8.0	abcd	8.2	abc	7.7	cdefghi	8.4	ab
Simplesse	6.7	mnopqrs	7.4	fghijklm	7.8	cdefghi	7.7	cdefghi	8.2	abc
Intermediate (55)										
Betatrim	6.4	pqrstuvw	6.8	lmnopqr	6.9	klmnopq	7.1	ijklmno	7.3	ghijklmn
Stardri	6.9	jklmnopqr	8.0	abcde	8.0	abcdef	7.8	abcdefgh	8.5	a
Simplesse	6.7	nopqrstu	7.0	jklmnop	7.2	hijklmno	6.7	nopqrst	7.5	defghij
Low (75)										
Betatrim	6.1	stuvw	6.0	vw	5.9	w	6.0	uvw	6.2	rstuvw
Stardri	6.8	lmnopqr	7.9	cdefgh	7.4	fghijklm	7.8	bcdefgh	8.2	abc
Simplesse	5.9	w	6.6	opqrstuv	7.0	jklmnop	6.7	mnopqrst	6.8	lmnopq

[a] Least-squares mean estimates of cookie spreads across 4 flour protein levels.
[b] Least-squares mean estimates with unlike letters are significantly different ($p = 0.0244$); standard error of the mean = 0.32.
[c] Cookie spread calculated as width (cm) of 2 cookies/height (cm) of 2 cookies per treatment; average of 4 width measurements per cookie and average of 2 height measurements per cookie.

Except for Isomalt at 45%, Betatrim at 75% fat reduction combined with the polyols, resulted in reduced cookie spreads compared to the respective full-fat/polyol variations (Table III-6). Simplesse 75% with most of the polyol treatments produced spread values similar to the full-fat/polyol combinations. This is of little practical importance because the spreads for most cookies with a 75% fat reduction were generally below the industry standard. Stardri fat replacement at 75% was the only exception to this, in which the incorporation of any sugar replacer/sugar level caused cookie spread to be within or above the 7.5-7.9 range.

As reported in Table D-1 (Appendix D) the control treatment produced cookies spreads below the accepted 7.5-7.9 range when the 3 higher protein flours were used. Although the interaction of FPRO X FATR X FATL X SUGR X SUGARL was not significant for cookie spread, these results suggest that the 4th break flour used in this study would not be appropriate for cookie production. The 2 polyols used in this study actually improved cookie dough properties for even the higher protein flours, resulting in increased cookie spread. The larger spreads produced when sugar replacers were incorporated may be off-setting the diminished flour performance which may explain why the interactions involving flour and sugar replacer were not significant.

The increased spreads that were seen overall in the fat replacer/sugar replacer combinations when compared to the control cookie suggest that dough consistency was lowered when these macronutrient replacers were combined. The increased spreads may have been attributed to the hygroscopic behavior of the fat replacers and the similar properties the polyols have to sucrose. Polyols possess similar solubility and viscosity (70% solution) to sucrose and the reduced concentration of sucrose was also able to completely dissolve (Olinger and Velasco 1996).

Cookie Hardness

FPRO X FATR X FATL was significant for cookie hardness ($p = 0.0053$) (Table III-7). Overall, less force was needed to penetrate full-fat or fat-reduced cookies as flour protein increased. Other researchers have shown harder cookie textures with higher flour protein contents (Gaines and others 1992b). Cookie-set supposedly occurs sooner when increased flour protein is present. When cookies set earlier, cookie spreads are reduced. The reduced surface area does not permit moisture loss from the cookies during baking which results in moister, softer textures. The 7.5-min bake time may also not have been sufficient to remove the excess moisture.

When each fat replacer at the various fat levels is compared to the full-fat treatment for the respective flours, differences in cookie hardness were observed (Table III-7). Stardri fat replacement at all levels produced harder cookies than the full-fat cookies. Stardri cookies were also harder than all other fat-reduced cookies. Simplesse cookie hardness was similar to the full-fat/flour counterparts. Except for 35% fat replacement, Betatrim cookies became softer than the full-fat cookies for the 3 lower protein flours. When flour protein was increased to 10.4%, Betatrim cookies were similar to the full-fat. The 10.4% protein flour cookies were softest. Stardri was the only replacer that was able to produce a cookie hardness better than the full-fat cookie using the 10.4% flour. In fact, cookie hardness for the 10.4% protein flour was similar to the full-fat /5.8% protein flour cookie, when Stardri replacement was used.

The harder and more consistent cookie texture among all levels of Stardri fat replacement and flour protein content suggests that increased carbohydrate-carbohydrate interactions may occur with the added maltodextrins (Nonaka 1997; Setser and Racette 1992). The increased spreads that Stardri fat replacement

Table III-7–Least-squares mean[ab] estimates of wire-cut cookie hardness[cd] as a function of flour protein content and fat replacer within fat level

Fat level (%)	Flour protein level (%)[e]							
Fat replacer	5.8		7.5		8.8		10.4	
Full fat	1245	defghij	1040	hijklmno	812	nopqr	609	r
Reduced (35)								
Betatrim	1160	efghijkl	1084	fghijklmn	870	lmnopqr	739	pqr
Stardri	2190	a	1383	cde	1207	defghij	1010	jklmnop
Simplesse	1351	def	1029	ijklmno	864	mnopqr	718	qr
Intermediate (55)								
Betatrim	851	mnopqr	699	qr	679	qr	600	r
Stardri	1650	bc	1351	defg	1306	defghi	1128	efghijklm
Simplesse	1309	defgh	926	klmnopq	803	nopqr	644	qr
Low (75)								
Betatrim	706	qr	663	qr	701	qr	662	qr
Stardri	1823	b	1470	cd	1231	defghij	1197	defghijk
Simplesse	1068	ghijklmn	902	lmnopq	769	opqr	763	opqr

[a] Least-squares mean estimates of wire-cut cookie hardness values across sugar/sugar replacer system.
[b] Least-squares mean estimates with unlike letters are significantly different ($p = 0.0053$); range of standard error of the means = 107-111.
[c] Cookie hardness evaluated with a texture analyzer (TA.TXT2 Texture Technologies, Scarsdale, NY) affixed with a TA-53 3mm probe.
[d] Hardness (g) values are the average of 7 probes per cookie (1 center probe + 6 side probes equidistant from center probe) and 2 cookies per treatment combination.
[e] Adjusted to a 14% moisture basis.

produced may permit greater surface drying and thus harder textures. Simplesse cookie texture was more similar to the full-fat cookie textures. Simplesse may act as a dough conditioner and emulsifier, extending what fat was present in the system. Hydrophilic properties of the protein-based fat replacer may help control water binding for moistness; hydrophobic properties maintain the shortened texture. Betatrim fat replacement on the other hand appeared to become softer as fat replacement increased to 55 and 75%. The increased hydration of this fat replacer may have contributed to the softer textures at these higher levels of fat reduction.

The peak profiles of the different fat treatments provide some indication of how the fat replacers are performing in the cookie matrix (Figure III-6). Stardri and Simplesse produced a series of peaks most similar to the full-fat cookie. The profiles suggest that layering and gas pocket formation was present giving some degree of fracturability to the cookies. When the Betatrim cookie was probed fewer peaks were produced and a valley between the initial penetration and exit from the bottom crust was present. This suggests that Betatrim was not able to produce the desirable layering and crispness needed for the traditional "snap" characteristic associated with this type of cookie. A more cake-like or chewier texture was most likely produced with Betatrim fat replacement.

Cookie hardness was also affected by SUGR X SUGL ($p = 0.0003$). Maltitol at both levels produced the hardest cookies. Isomalt and full-sugar cookies were similar in hardness. The effects of FPRO X SUGR X SUGL, FATR X FATL X SUGR X SUGL, and FPRO X FATR X FATL X SUGR X SUGL were not significant for cookie hardness.

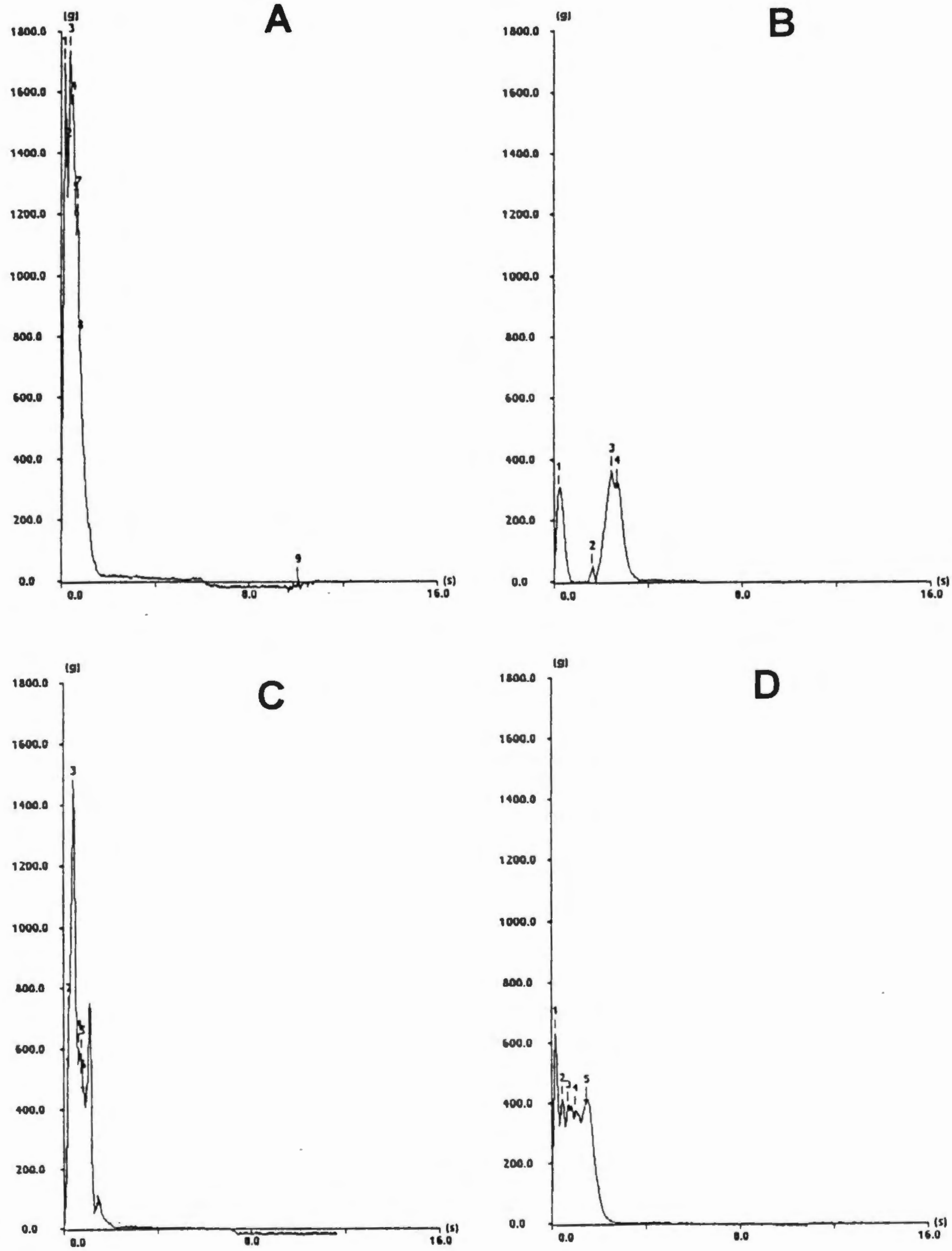

Figure III-6– Profiles of single probe hardness measurements of wire-cut cookies formulated with full fat and 3 fat replacers, 8.5% protein flour/full sugar (A = full fat, B = Betatrim, C = Stardri, D = Simplesse).

Summary, Conclusions, and Implications

Cookie spread and cookie texture are important quality measurements that are used to assess both flour quality and the performance of different ingredients in the cookie system. The wire-cut cookie formula utilized in this study normally contains high proportions of fat and sugar. When the formula was modified using flours of various protein contents and fat- and sugar replacers, significant differences in cookie spread and hardness were found.

Flour protein content was important to cookie quality when fat replacers were used. This study agreed with previous studies in which cookie spread decreased when flour protein content increased (Gaines 1985; Kaldy and Rubenthaler 1987; Labuschagne and others 1997). This investigation showed that as water content increased with the use of fat replacers, flour hydration properties became more important. Higher protein content in flours increased flour water retention capacity.

The wire-cut cookie is a low-moisture system. Less water absorption by the low-protein flours permitted sucrose to be completely dissolved and therefore cookies achieved maximum spread (Yamazaki 1962). The larger spreads permitted increased moisture loss during baking which produced harder cookies. Other researchers have shown cookie hardness increases when high-protein flours are used (Gaines and others 1992b; Hoseney 1986; Manley 1991). These conflicting results may be explained by the fact that flours used in these reported studies were from different wheat cultivars. The 4 flours used in this investigation were different in protein content as a direct consequence of stream selection. Therefore, quality of the endosperm after the 1st and 4th breaks may have introduced another factor critical to the performance of the flours. It is possible the 4th break resulted in damaged starch, ultimately increasing water retention capacity of this flour.

The significant interaction between FPRO X FATR X FATL on cookie spread and texture indicated that a flour with optimal absorption properties is ideal. Hygroscopic fat replacers will hold water and affect water mobility in cookie dough differently. The 2 carbohydrate-based fat replacers, Betatrim and Stardri, produced cookies with different spread and hardness. Excess moisture from hydration of the fat replacer was detrimental to Betatrim cookie quality when fat reduction exceeded 35%. Stardri cookies, however, were larger and harder than the other fat replacers and full-fat cookies; these results were also consistent among the 4 flour protein levels. The differences between Betatrim and Stardri may be attributed to how cookie set-time was controlled. The maltodextrin Stardri was able to delay this set-time by competing for water and preventing the glass transition temperature from being reached too early.

The protein-based fat replacer, Simplesse, produced cookies most similar to full-fat, especially when cookie hardness results are compared. Armbrister and Setser (1994) also found that Simplesse containing chocolate-chip cookies exhibited textural parameters most like the control fat cookies. Besides participating in water reactions, the protein-based fat replacer may be extending the function of the shortening present in the reduced-fat formulas.

Product optimization of the wire-cut cookie would depend on selection of an ideal fat replacement system that would mimic a full-fat version. Based on texture and cookie spreads, each fat replacer used in this study produced acceptable products; however, each fat replacer was effective at different levels. Flour protein level was also more important for some fat replacer systems and also affected the extent of fat reduction. Higher levels of Simplesse and Stardri replacement produced larger cookies and textures were more like the full-fat cookies when the lower protein flours were used; however Betatrim produced the most optimum cookie spread and hardness when fat-reduction was only 35%.

Sugar replacers were also incorporated into the reduced-calorie cookies. An interaction between flour protein, sugar replacement and sugar level was not significant, but the combinations of sugar- and fat replacers did have an effect on cookie spread. In general, cookie spreads were larger for the reduced-calorie combinations. These increased cookie spreads may have been attributed to the high solubility and low hygroscopicity of the polyol sugar replacers which decreased dough consistency. These cookie doughs would spread faster during baking. The low hygroscopicity of the polyols may be advantageous in the high moisture fat replacer systems by improving shelf-life of the reduced-fat cookies (Nonaka 1997; Olinger and Velasco 1996). Further investigation of this is warranted.

In conclusion, flour protein content needs to be considered when formulating reduced-fat cookies. In this study, the relationship between flour protein content and the water retentive properties were most critical to flour performance. Further investigation of this relationship is needed. Sensory evaluation is needed not only to determine if fat and/or sugar replacers can successfully mimic full-fat/full-sugar counterparts, but also to examine if differences in flour quality can be detected. Instrumental assessment of texture met the objectives of this study, but how these results would agree with sensory ratings is of interest. Cookie texture is multifaceted, and one instrumental technique may not suffice for accurately assessing product texture. It is known that flour quality is of utmost importance to product quality. This study confirms that flour quality, which includes but is not limited to protein content, needs consideration when formulating reduced-calorie products.

Chapter IV

EVALUATION OF COOKIE SPREAD, HARDNESS, AND SENSORY EVALUATION OF A MACRO WIRE-CUT COOKIE FORMULATED AT 3 FLOUR PROTEIN LEVELS, 3 FAT REPLACERS, AND 2 SUGAR REPLACERS

Abstract

A randomized incomplete block design, blocked on day and panelist was used to study the effects of flour protein content, fat replacer, and sugar replacer on wire-cut cookie quality. A trained sensory panel (n=12) evaluated wire-cut cookies formulated at of 3 flour protein levels (5.5, 7.3, and 8.8%), 3 fat replacers (Betatrim, Stardri, and Simplesse at 35, 55, and 55% fat reduction, respectively) and 2 sugar replacers (Maltitol and Isomalt, both at 65% sugar reduction).

Full-fat and Simplesse cookies with the 5.5% protein flour were darker than all other cookies ($p = 0.0045$). Isomalt cookies with any fat replacer were similar in baked color to the control and Betatrim cookies with sugar or Maltitol were lighter than control cookies ($p = 0.0075$). Full-fat/low-protein flour cookies were drier ($p = 0.0007$) and had rougher surfaces ($p = 0.0184$) than all other cookies. Control cookies were driest and Simplesse cookies with sugar replacers were moistest ($p = 0.0025$). Control cookies and Stardri cookies with any sugar system, were harder than all Betatrim and Simplesse cookies ($p = 0.0251$). Cookies made with the low-protein flour had larger crumb cell size ($p < 0.0001$), were more brittle ($p = 0.0005$), were more likely to tooth pack ($p = 0.0009$), had more intense browned flavor ($p = 0.0150$) and were sweeter ($p = 0.0003$) than cookies made with the higher protein flours. Browned flavor was more intense for full-fat cookies ($p = 0.0174$) and sugar replacers were associated with more intense aftertaste in the cookies ($p = 0.0018$).

Bakers must formulate reduced-fat cookies with low-protein flours to produce products most similar in appearance and texture to a full-fat version. Formulators can also select fat/sugar replacer combinations that will produce cookies similar in texture to that of full-fat and full-sugar counterparts.

Introduction

Protein content of flour is important to soft-wheat product quality. This flour attribute has been correlated with cookie diameter and cookie texture, two indicators of flour quality. When cookie flour is above the usual 7.5-8.5% protein, cookie diameter has been shown to decrease and a hard texture is likely (Kaldy and Rubenthaler 1987; Pyler 1988). If high-protein flours are used, formulas must be increased in sugar and fat to retain tenderness (Pyler 1988).

To meet consumer demand, cookies are often formulated with fat and sugar replacers to reduce calories. Research is directed toward product optimization of reduced-calorie products to determine the most ideal fat- or sugar-replacer and the highest level of reduction that will match a full-fat and full-sugar counterpart (Armbrister and Setser 1994; Olinger and Velasco 1996; Sanchez and others 1995). Lipid, protein, or carbohydrate-based ingredients are used as fat replacers. Sugar alcohols (polyols) are common bulking agents used in sugar replacement. These ingredients will ultimately change the cookie system, and flour protein may impact the final quality of the reduced-calorie product.

The previous experiment (Part 1)(Chapter III) showed that a cookie system was altered when fat and sugar replacers were incorporated into a wire-cut cookie formula, which is often used to assess potential flour baking performance (AACC 2000). Four flour protein levels were also examined. A significant interaction between fat replacer, fat level, and flour protein level was found for cookie spread and instrumental cookie hardness. Optimal cookie formulas were selected based on these measurements. In general, full-fat and reduced-fat cookie quality improved with the lower protein flours. An interaction between sugar replacement and fat replacement was also found to affect cookie quality. Sugar replacer and fat replacer combinations increased cookie spread when compared to full-fat/full-sugar cookies. Texture was studied using an instrumental probing technique. Cookies were found to be harder when lower protein flours were used; however the addition of fat replacers had a more varied effect on cookie hardness than did variation in flour protein. Cookie hardness also increased when a sugar replacer was incorporated.

Although this previous experiment demonstrated that cookie quality was changed when fat replacers and sugar replacers were used with various flour protein levels, further investigation is warranted. Instrumental methods must be sensitive to small degrees of variability and best correlate with sensory evaluation. Sensory evaluation is not often utilized in baking quality tests for assessment of flour quality, but product optimization is key. Therefore, investigation of the use of sensory evaluation as a tool in assessing flour quality and the performance of fat replacers and sugar replacers in a standardized baking quality test is of interest. The objectives of this experiment (Part 2 of a 2-part study) were:

1. To characterize flours of 3 protein levels in order to examine the effect of flour protein content and other flour attributes on wire-cut cookie quality.

2. To test for differences in cookie spread and cookie hardness by utilizing 30

pre-selected wire-cut cookie formulations which are various combinations of 3 flour protein levels, 3 fat replacers, and/or 2 sugar replacers, and a full-fat/full-sugar treatment.

3. To develop a lexicon of cookie attributes that could be utilized for sensory evaluation of the standardized wire-cut cookie method.

4. To use a descriptive sensory evaluation method in order to quantify the effects of flour protein content, fat system, and/or sugar system and the interaction among these variables on cookie appearance, texture, and/or flavor.

5. To correlate sensory measurements of cookie texture and color with instrumental values of cookie hardness and Minolta L*, a* and b* and hue angle in order to determine if instrumental results are predictors of sensory evaluation of product attributes.

6. To compare nutritional contents of the 30 wire-cut cookie formulations.

Materials and Methods

Experimental Design

Sensory evaluation of 30 reduced-calorie cookie formulations was conducted using a randomized balanced incomplete block design. The macro wire-cut cookie formula and method 10-53 (AACC 2000) was adapted for various treatment combinations of 3 flour protein levels, 3 fat replacers, and 2 sugar replacers (Tables IV-1, 2, and 3). Eleven sensory attributes of the cookies were evaluated by a 12-member trained sensory panel. Days were blocked in the incomplete implementation and panelists were blocked over the complete design.

Table IV-1–Basic macro[a] wire-cut cookie formula

Ingredient	Weight (g)	Flour weight basis (%)
Flour, 13% moisture basis[b]	225.0	100.00
Fat/fat replacer system[c]	90.0	40.00
Sugar/sugar replacer system[d]	94.5	44.00
High-fructose corn syrup, 42%[e]	3.4	1.50
Salt[f]	2.8	1.20
Nonfat dry milk[g]	2.3	1.00
Sodium bicarbonate[h]	2.3	1.00
Ammonium bicarbonate[i]	1.1	0.50
Natural almond flavoring[j]	0.5	0.22
Water, deionized[b]	49.5	22.00

[a] Formulation amounts for 12 cookies; adapted from method 10-53 (AACC 2000).
[b] Final weight of flour with water adjusted to 13% moisture basis to give equivalent of 225 g (White Lily Foods Co., Knoxville, TN).
[c] Components shown in Table IV-2.
[d] Components shown in Table IV-3.
[e] Cargill Inc., Dayton, OH.
[f] Morton® Salt, Chicago, IL.
[g] Armour Food Ingredients, Springfield, KY.
[h] Arm & Hammer®, Church & Dwight Co., Inc., Princeton, NJ.
[i] Vitusa Products Inc., Berkeley Heights, NJ.
[j] Givaudan-Roure, Clifton, NJ.

Table IV-2–Fat/fat replacer systems for macro[a] wire-cut cookie formula

Fat reduction (%) Fat replacer	HVO[b]	Fat replacer	Water	Mono- and diglycerides[c]	Lecithin[d]	Polydextrose[e]
	Ingredients					
	---g---					
Full fat (0)	90.0	-	-	-	-	-
Reduced fat (35)						
Betatrim[f]	53.8	5.4	16.1	4.7	1.5	8.5
Moderate fat (55)						
Stardri[g]	35.8	10.8	23.8	4.7	1.5	13.4
Simplesse[h]	35.8	11.5	23.1	4.7	1.5	13.4

[a] formulation amounts for 12 cookies; adapted from method 10-53 (AACC 2000).
[b] hydrogenated vegetable oil (CreamTex®, Ventura Foods, Inc., City of Industry, CA.).
[c] mono-/diglycerides enriched with BHT and citric acid (Dur Lo®, Loders Croklaan, Glen Ellyn, IL).
[d] phosphatidylcholine-enriched soybean lecithin (Lecimulthin 130®, Lucas Meyers, Decatur, IL).
[e] StaLite III (A.E. Staley, Decatur, IL).
[f] hydrolyzed oat flour (Rhodia Food Ingredients, Cranbury, NJ).
[g] maltodextrin (A.E. Staley, Decatur, IL).
[h] microparticulated whey protein (Kelco Biopolymers, San Diego, CA).

Table IV-3– Sugar/sugar replacer systems for macro[a] wire-cut cookie formula

Sugar reduction (%) Sugar replacer	Sucrose, fine granulated[b]	Sucrose, brownulated granulated[c]	Sugar replacer	Ace- K [d]	Polydextrose [e]
	Ingredients				
	---g---				
Full sugar (0)	72.0	22.5	-	-	-
Reduced sugar (65)					
Isomalt [f]	37.0	15.0	31.5	0.2	10.8
Maltitol [g]	37.0	15.0	31.5	0.2	10.8

[a] Formulation amounts for 12 cookies; adapted from method 10-53 (AACC 2000).
[b] Kroger's, Cincinnati, OH.
[c] Domino Specialty Ingredients, Baltimore, MD.
[d] Sunette Brand®, Nutrinova Inc., Somerset, NJ.
[e] StaLite III®, A.E. Staley, Decatur, IL.
[f] Polyol (isomaltulose); Palatinit-Subungsmittel Gmblt Mannheim, W.Germany.
[g] Polyol (hydrogenated maltose); Maltisorb®P200, Roquette America, Inc., Keokuk, IA.

Cookie doughs were prepared and refrigerated (4°C) overnight in air-tight plastic containers 2 d prior to sensory testing. On the next day, cookies were baked, cooled, and stored in coded resealable plastic bags and stored overnight. Sensory evaluation was then completed over the course of 2 d which included an afternoon session, and a morning and afternoon session on the next day in order to ensure testing was completed within 2 d post-bake. This process was repeated to complete one replication.

After each 3-session sensory testing period, cookie samples were prepared and measured for water activity, moisture, and instrumental hardness measurements. Cookie samples were also frozen (-18°C) for additional testing which included color measurements, fat, and protein determination. These latter tests were completed at the end of the study. Results from the physical and chemical tests were analyzed with the same randomized balanced incomplete block design with treatments blocked on baking day.

Experimental Material

Flours

The 3 flour protein levels were produced in the same manner as the previous study. However, a new batch of the low-protein flour (1st break) was obtained as a result of infestation of the first batch. The high-protein flour (4th break) from the previous experiment was used in blending of the 2 intermediate protein levels, but was not used alone for experimental testing. The 2 intermediate flours were produced by blending 66% high-protein flour plus 34% high-protein flour and 34% low-protein flour plus 66% high-protein flour. Each flour (44 kg) was blended for 7 min on Speed 1 in a

20-L Hobart® planetary mixer equipped with a flat beater attachment (Model A-200 Hobart Co., Troy, OH). Each flour was transferred to 4, 2-L air-tight Mason® jars (Ball Corp., Munice, IN), stored at -18°C, and tempered to room temperature 1 d prior to testing.

Reduced-Fat and Reduced-Sugar Cookie Formulas

Formulas for wire-cut cookies for this study were selected on the basis of Part 1 results. Comparisons of cookie spread and texture among the various test formulations and to accepted standards were made. Ideal wire-cut cookie spread of 7.5-7.9 has been suggested for high pastry flour quality (Anonymous 2001). In Part 1, the main effect of flour protein was significant, with the lower protein flour producing larger cookies and greater hardness values ($p < 0.0001$). Within all treatment combinations, the highest flour protein flour consistently produced cookie spreads and hardness values that were significantly below standards and/or different from the control fat and sugar treatments. Therefore, this flour was eliminated for further study.

An interaction between FPRO X FATR X FATL existed for cookie spread and cookie hardness ($p<0.0001$); therefore 3 fat replacers were selected. Fat replacer/fat reduction level selection was based on performance compared to the control treatments within each flour protein level. FATR X FATL X SUGR X SUGL was also significant for cookie spread ($p=0.0244$) , therefore sugar replacers were considered for combination with fat treatments. FPRO X SUGR X SUGL interaction was not significant, thus using the control sugar formula with all fat and flour treatments was not of interest.

First, a control (full-fat/full-sugar) treatment was used to represent what is produced commercially. The 3 fat replacers selected for this study included a hydrolyzed oat flour (Betatrim™), a maltodextrin (Stardri®), and a microparticulated protein fat mimetic (Simplesse®) at fat replacement levels of 35, 55, and 55% respectively (Table IV-2). In Part 1, cookie spread and texture values for cookies made with these fat replacers at the respective levels were found to be similar to control treatments or met or exceeded industry standards.

Treatments were also compared in order to select sugar replacers. Isomalt® and Maltitol, 2 sugar polyols, were found to produce similar or larger cookie spreads than the control sugar cookie. Maltitol sugar replacement produced harder cookies and larger spreads compared to control sugar and Isomalt. Isomalt had values similar to the control. Sugar reduction levels of 45 and 65% were tested; however 65% sugar reduction level for both replacers was selected because cookie spread or texture was not compromised. Sugar replacers were combined with the 3 selected fat replacers, control fat, and 3 flours protein levels.

Polydextrose, lecithin, and a mono- and diglyceride emulsifier were added to all formulas to improve texture, mouthfeel, and dough handling as suggested in previous studies (Hodgson and others 1993) and concluded during preliminary work. Polydextrose was also added to each reduced sugar formula to a 10% level of the sugar replacer content. Acesulfame-K, a high intensity sweetener, was added to both polyol treatments for similar sweetness to the control sugar.

Formulations for fat and sugar reductions were designed to meet the legal definitions for "reduced-fat", "reduced-sugar", and "reduced-calorie". Fat, sugar, and calorie contents were projected to meet or exceed the 25% less fat, sugar, and/or calories per serving requirement (FDA 2000).

Experimental Procedures

Flour Characterization

As described in Chapter III, percentage protein, moisture, ash, AWRC, and flour pH were determined for each flour in triplicate. Mixograms for each flour were produced in triplicate according to the procedures described in Chapter III.

Mixing and Baking Procedures

Mixing and baking of the macro wire-cut cookies were followed according to the procedures outlined in Method 10-53 (AACC 2000) with some modifications. The basic formula and the fat and sugar systems used are presented in Tables IV-1, -2, and -3 respectively. Flour moisture was determined within 24 h of dough preparation in order to adjust flour to a 13% moisture basis.

Except for flour and ammonium bicarbonate, dry ingredients were pre-weighed and stored in plastic air-tight containers. Dry ingredients also included fat replacer and sugar replacer systems. One day prior to baking, these dry ingredients were combined with the shortening to produce a creamed mass. According to the AACC method 10-53 (2000), multiple batch preparation of the creamed mass is recommended to reduce variation. Therefore, a 3-batch creamed mass mixture, later divided among the 3 different flours, was prepared by tumbling the dry ingredients in a 2-L glass jar for 20 rotations. The dry ingredient mixture was then poured on top of the pre-weighed hydrogenated shortening and mono- and diglycerides and creamed in a mixer equipped with a flat-beater attachment on STIR speed for 3 min (Kitchen Aid®, Model K45SS, St. Joseph, MI). The 3-batch creamed mass was weighed and divided into 3 equal portions that were then mixed with the appropriate flours.

In a 100-mL beaker, HFCS and ammonium bicarbonate were swirled with the water. The moistened creamed mass was mixed in a second mixer equipped with a flat-beater attachment (Kitchen Aid®, Model K5SS, St. Joseph, MI) on Speed 2 for 1 min, scraped, and mixed on Speed 4 for 1 min. Flour was then added to the creamed mass and mixed on STIR Speed for 2 min, scraping every 30 sec. Cookie doughs were stored in air-tight plastic containers and refrigerated overnight (4°C).

After tempering for 1 h, each cookie dough treatment was divided into 12, 37-g portions, placed on 2 aluminum cookie sheets lined with parchment paper (6 cookies per sheet), and rolled to 7-mm thickness. A gauze-covered wood rolling pin was used to prevent sticking. Doughs were cut with a stainless steel 60-mm diameter cutter, trimmed of excess dough, and baked in a 205°C rotary oven (National Manufacturing Co., Lincoln, NE) for 7.5 min. Baked cookies were cooled 5 min on wire racks, removed from the aluminum baking sheet (remained on parchment paper), and cooled for an additional 60 min. Cookies were stored at 25°C in coded resealable sandwich bags (Kroger Co., Cincinnati, OH) until sensory testing. Laboratory temperature and percent humidity were measured 3 times per day for 8 d which included dough mixing and baking days. Average values were 23°C ± 0.5 and 31.5% ± 4.4, respectively.

Product Evaluation

<u>Proximate analysis</u>. One cookie from each treatment, was ground with a mortar and pestle, and percentage moisture, protein, and ash were determined in duplicate for all

cookie treatments using methods described previously for flour analysis (Part 1, Chapter III). Moisture contents of the cookies were determined within 2-d post-bake and dried cookie samples (~2 g) were transferred to weighed Number 1 filter papers (Whatman®,1001-110), folded/stapled, and held (-18°C) until needed for fat determination. Values for protein, fat, and ash contents were adjusted to a 13% moisture basis because cookie doughs were prepared with flour adjusted to this level.

Fat content was determined by Soxhlet extraction (Carden 1997; Min 1994). A 5000-mL round bottom flask containing ~4000-mL petroleum ether (b.p. 35-38°C, Fisher Scientific, Fair Lawn, NJ) was placed in a Glas-Col heating unit at heat setting 35. Samples were extracted for 4 h, removed from the Soxhlet, air-dried, and placed in a desiccator until weighed. Final weights (to the nearest 0.01 g) were used to determine fat lost. Percentage fat was calculated on a wet basis.

Carbohydrate content was determined by difference. Caloric determination was based on percentages of protein, fat, ash, and estimated carbohydrate. Energy densities of 2 kcal/g and 2.1 kcal/g were used for Isomalt and Maltitol, respectively, because polyols are partially digested (Palatinit of America, Inc, Morris Plains, NJ; Roquette of America, Inc, Keokuk, IA). Polydextrose, also used as part of the fat and sugar replacement, is partially digested, providing ~1 kcal/g (A.E. Staley, Decatur, IL). These energy values were used to estimate caloric contribution from carbohydrate. Average energy values for a 1-cookie serving were calculated based on percentages fat, protein, and carbohydrate contents.

Water activity. Within 48 h post-bake, ground cookie samples (~2g) were placed in plastic dishes designed for use with an AquaLab Meter (Model CX-2, Decagon Devices, Pullman, WA). Water activity (a_w) was determined in duplicate.

Cookie spread. Cookie spread was determined using the procedures described in Part 1 (Chapter III). However, 4 cookies were used for width and thickness measurements. Cookie spread was calculated as width over thickness, averaged, and reported.

Cookie hardness. Two days post-bake, a TA.TXT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY), equipped with a 3-mm diameter probe, was used to evaluate cookie hardness according to the procedure described in Part 1 (Chapter III) (Appendix A). Two cookies per treatment were analyzed. Maximum peak force was recorded for each probe, and the 7 probe values were averaged for mean peak force.

Color evaluation. Colorimetric analysis was performed on baked cookies with a Minolta CM 508 tristimulus color analyzer (Ramsey, NJ). Interpretation of the Minolta L*, a*, and b* values is similar to the standard Hunter L a b values. The primary difference between these methods is that the range for the yellowness/blueness scale (b value) has been extended (Mount 2001). Before measurements were taken, the Minolta was calibrated against space to account for stray light and with a Minolta C2-21128 beige calibration tile (Ramsey, NJ). The light source used was illuminant C, candescent and the object was viewed at 10° from the source. The color values were recorded as Hunter L*, a*, b*, where L*=light/dark, a*=green/red and b*=yellow/blue; hue angle or $\tan^{-1}(b/a)$ was calculated. Two cookies per treatment were measured. To account for color variation within one cookie, each cookie was measured at 3 random positions on the cookie surface.

Sensory Evaluation

Twelve panelists were recruited from the College of Agricultural Sciences and Natural Resources at The University of Tennessee at Knoxville. A descriptive sensory technique was used and panelists were trained for 4 h in 2 sessions on terminology and reference products. Attributes and anchors for each attribute were defined (Appendix E). Reference products were chosen to represent the anchors and/or mid-points of a 0-150 mm unstructured line scale that was used for rating each attribute. Actual samples of reference products were provided to the panelists during training sessions. Panelists were also familiarized with the computerized sensory program (Resurreccion 1993) used to collect the data. A practice day that simulated an actual panel was used to confirm if panelists understood the instructions.

Cookies were evaluated for appearance, texture, and flavor attributes. Intensities of baked color and internal cell size were two appearance attributes assessed. Texture was assessed for surface roughness, hardness, fracturability, moistness, and molar packing. Flavor attributes included almond flavor, browned flavor, sweetness, and aftertaste. Along with instructions for completing a session, an attribute definition list with assigned reference product values was provided to the panelists; photographs for baked color and cell size were also used for reference (Appendix E).

In each session, each panelist evaluated 5 cookie treatments, which were presented in plastic resealable bags coded with random 3-digit codes. Presentation order of cookie treatments was also randomized for each of the 12 panelists over the complete design. Panelists received water for rinsing between samples, a styrofoam cup for expectoration if desired, and a plate and serrated knife to cut the cookie in half for assessment of cell size and evaluation of hardness. Hardness is the force required to bite completely though the sample placed between the molars (Muñoz 1986). Therefore, a piece (approximately 1 cm x 2 cm) was cut from the cookie sample by each panelist in order to evaluate hardness. All treatments were evaluated within 24-48 h post-bake.

Statistical Analysis

Cookie spread, hardness, proximate analysis, and water activity values were tested for equal variance (PROC MEANS, SAS Institute, Inc 2000). PROC UNIVARIATE (SAS Institute, Inc 2000) was used to test for normality of the data. Main effects and interaction effects among the variables of flour protein, fat replacer, and sugar replacer on cookie spread and hardness values were analyzed (PROC MIXED, SAS Institute, Inc 2000). Day and replication were random variables in the model. Data for all 11 sensory attributes were analyzed with the same procedures, with panelist, day, and replication as random factors in the model. Least-squares means were generated and the PDIFF function was used to test for significant differences (SAS Institute, Inc 2000).

PROC CORR (SAS Institute, Inc 2000) was used to test for relationships among treatment means for sensory attributes (baked color, cell size, hardness, fracturability, moistness, and molar packing) with mean values of instrumental data (color L*, a*, b*, hue angle, hardness, and cookie spreads). PROC GLM (SAS Institute, Inc 2000) was used to test for differences in flour protein, pH, AWRC, ash, moisture, and mixogram values. SAS programs for each data analysis step are provided in Appendix B.

Results and Discussion

Flour Characterization

Protein contents of the flours were 5.5, 7.3, and 8.8% (Table IV-4). As in Part 1, different milling streams were used to control protein. Flours did not statistically differ in ash content, although the proportion of the 4th break flour increased from 33 to 66% in the 7.3 and 8.8% protein flours, respectively. Bran and germ presence has been noted in flour from the 4th break because this milling step requires the fracture and crushing of the endosperm (Smith 2001).

Increasing flour protein content increased the water retentive properties of the test flours. The higher protein flours were significantly higher in AWRC than the 5.5% elevated AWRC values. Besides higher protein content, starch damage has also been protein flour. Inclusion of the 4th break flour in the higher protein flours may explain the noted to occur as increased pressure is applied to the endosperm (Posner and Hibbs 1997). High AWRC values have been positively correlated with increased starch damage (Gaines and others 1996).

Increasing flour protein content also resulted in differences in moisture absorption, peak height, development time, and angle of development as determined with a mixograph. With each increase in protein content, optimal dough absorption increased. Peak height, which is generally proportional to protein content, increased when flour protein increased from 5.5 to 7.3%; the higher protein flours were not significantly different in peak height. Angle of development significantly increased when flour protein was increased from 7.3 to 8.8% than did the lower protein flours. This indicates it took the 8.8% protein flour longer to develop a gluten matrix than did the lower protein flours. This finding is most likely a direct consequence of more protein being present rather than a difference in protein quality. The similar breakdown values among the flours also suggest that tolerance to overmixing was not affected and that flour quality (strength) is similar among the flours.

As previously discussed, flour pH in this experiment may be of little practical importance. Cookie flours are often intentionally chlorinated to a pH of 4.8 to effect limited cookie spread (Gaines and others 1988). The addition of leaveners generally increases alkalinity of cookie dough. Fat replacers have also been shown to increase

Table IV-4–Characteristics of flours

		Flour protein level (%)[a]					
Attribute	p value	5.5		7.3		8.8	
Ash (%)[a]	0.1262	0.24	a	0.30	a	0.39	a
AWRC (%)[a]	0.0113	64	a	69	b	72	b
Flour moisture (%)[b]	0.0036	13.6	a	12.7	b	11.2	c
pH	<0.0001	6.2	a	6.2	a	6.3	b
Mixograph [c]							
Optimal absorption (%)[d]		42.5		48.5		58.0	
Peak height (cm)	0.0033	3.3	a	4.1	b	4.2	b
Development time (min)	0.0101	3.9	a	4.5	a	6.4	b
Angle of development (°)	0.0077	3.3	a	2.8	a	6.8	b
Angle of breakdown (°)	1.0000	3.0	a	3.0	a	3.0	a

[a] Adjusted to a 14% moisture basis; all flour protein levels are significantly different (p<0.0001).
[b] Averaged over length of study (8 d).
[c] Measured with a mixograph (National Manufacturing, Lincoln, NE).
[d] Determined according to method 54-40A (AACC 2000).

cookie dough pH; however fat replacement has been found to decrease cookie spread (Swanson and others 1999). This suggests that the effect of fat replacement may override any effect of alkaline dough. Additional research is needed to confirm the role of flour pH, dough pH, and fat replacement on cookie spread.

Product Evaluation

Nutritional Composition of Cookies

Wire-cut cookie formulas used in this study were designed to be reduced in fat, sugar, and ultimately calories; therefore nutritional analysis of the 30 treatment combinations was of interest. Cookie samples (8 per treatment) were measured for moisture, fat, protein, and ash contents using standard proximate analysis methods. Fat, protein, and ash values were adjusted to a 13% moisture basis, and averaged; carbohydrate content was calculated by difference (Table IV-5). To evaluate the effect of flour protein level, fat replacer, sugar replacer, and the interaction among these variables on nutritional content of the cookies, least-squares means were analyzed for differences. According to the fixed effects models, differences in moisture, protein, fat, and ash contents were explained by the main effects of flour ($p < 0.0001$) and fat replacer ($p < 0.0001$) (Appendix C).

As flour protein level increased, cookie protein content increased from a mean of 3.7% to 4.8 and 5.5% ($p < 0.0001$). Flour protein level also affected cookie ash content ($p = 0.0070$). Ash contents of the 5.5% flour protein cookies (1.2% ± 0.02) were significantly lower than 7.3 (1.3% ± 0.02) and 8.8% (1.3% ± 0.02) protein flour cookies. The 4th break flour that was used in the 7.3 and 8.8% protein flours explains the elevated cookie ash contents.

Table IV-5 – Mean and standard deviations for percentage moisture, fat, protein, ash, and carbohydrate for 30 wire-cut cookie treatment combinations varying in flour protein content, fat replacer, and sugar replacer[a]

Wire-cut cookie formula			Moisture		Fat		Protein		Ash		CHO[b]
Flour protein %	Fat replacer	Sugar replacer					(%)				
5.5	Full-fat	Full-sugar	5.3	±1.2	17.7	±0.91	3.0	±0.09	1.2	±0.03	72.8
	Betatrim[c]	Full-sugar	8.8	±1.4	12.5	±1.5	3.0	±0.43	1.2	±0.09	74.5
		Isomalt[d]	8.3	±0.43	12.2	±0.76	3.2	±0.10	1.3	±0.08	75.0
		Maltitol[d]	8.6	±0.46	12.3	±0.74	3.2	±0.06	1.0	±0.04	74.9
	Stardri[c]	Full-sugar	9.8	±1.8	8.4	±1.0	3.3	±0.13	1.1	±0.25	77.4
		Isomalt	10.2	±1.8	7.8	±1.0	3.3	±0.15	1.2	±0.06	75.5
		Maltitol	10.1	±1.6	8.0	±0.60	3.3	±0.11	1.2	±0.12	77.4
	Simplesse[c]	Full-sugar	10.2	±0.53	9.2	±1.2	4.4	±0.07	1.4	±0.08	74.8
		Isomalt	10.0	±1.2	8.2	±0.88	4.4	±0.45	1.4	±0.08	76.0
		Maltitol	10.4	±0.65	8.9	±1.5	4.4	±0.16	1.4	±0.02	74.9
7.3	Full-fat	Full-sugar	6.3	±0.79	18.1	±1.6	4.0	±0.06	1.2	±0.06	70.4
	Betatrim	Full-sugar	8.4	±1.2	13.5	±1.7	4.2	±0.14	1.2	±0.06	72.7
		Isomalt	9.2	±0.87	12.3	±1.6	4.2	±0.39	1.3	±0.06	73.0
		Maltitol	7.7	±0.86	13.0	±0.91	4.3	±0.23	1.2	±0.12	73.8
	Stardri	Full-sugar	10.5	±1.4	8.2	±1.3	4.2	±0.22	1.3	±0.07	75.8
		Isomalt	9.9	±1.6	7.9	±1.8	4.2	±0.20	1.3	±0.04	76.7
		Maltitol	10.0	±2.1	7.9	±1.8	4.4	±0.58	1.3	±0.13	76.4
	Simplesse	Full-sugar	10.0	±0.53	8.5	±1.4	5.4	±0.17	1.4	±0.06	74.7
		Isomalt	10.5	±1.8	7.8	±1.4	5.3	±0.26	1.4	±0.07	75.0
		Maltitol	10.4	±2.3	8.4	±1.4	5.4	±0.21	1.3	±0.16	74.5
8.8	Full-fat	Full-sugar	6.4	±1.2	18.3	±1.4	4.7	±0.18	1.2	±0.08	69.4
	Betatrim	Full-sugar	9.0	±1.4	12.4	±2.1	4.9	±0.13	1.3	±0.03	72.4
		Isomalt	9.1	±1.2	12.6	±2.0	5.0	±0.13	1.3	±0.07	72.0
		Maltitol	8.4	±0.83	13.8	±0.92	4.9	±0.08	1.2	±0.13	71.7
	Stardri	Full-sugar	10.5	±1.0	8.9	±1.3	5.0	±0.11	1.4	±0.07	74.2
		Isomalt	10.2	±0.91	7.5	±1.0	5.0	±0.20	1.3	±0.07	76.0
		Maltitol	10.0	±0.77	7.7	±0.97	5.0	±0.13	1.3	±0.11	76.0
	Simplesse	Full-sugar	10.7	±0.88	9.4	±3.5	6.0	±0.39	1.4	±0.06	72.5
		Isomalt	10.9	±0.60	7.7	±1.0	6.2	±0.20	1.5	±0.04	73.7
		Maltitol	10.6	±1.2	8.7	±1.5	6.2	±0.36	1.4	±0.18	73.1

[a] Average of 8 treatments (duplicate samples for 2 baking days with 1 replication); values adjusted to a 13% moisture basis.
[b] Carbohydrate calculated by difference (100-%ash-%protein-%fat-%moisture).
[c] Fat reduction formulated at 35, 55, and 55% for Betatrim, Stardri, Simplesse, respectively.
[d] Sugar reduction for both Isomalt and Maltitol at 65%.

Ash, moisture, protein, and fat content differences in the cookies were also related to fat replacer (Table IV-6). Simplesse, a microparticulated whey protein, produced cookies with higher protein contents ($p < 0.0001$). Betatrim and Stardri, two carbohydrate-based fat replacers, were similar in protein content and were not different from the full-fat cookies. Simplesse cookies were also significantly higher in ash content than all other cookie fat treatments.

Fat replacer was also significant for differences in cookie moisture and fat contents ($p < 0.0001$). Results suggest, however, that the level of fat reduction was more important to this difference than type of fat replacer. As presented in Table IV-6, full-fat cookies had the lowest moisture content; moisture content of cookies with Betatrim at 35% fat reduction was significantly higher. Stardri and Simplesse at 55% fat replacement produced significantly higher cookie moisture contents. In all cases, the water added to hydrate the fat replacers increased moisture contents of the cookies as confirmed in earlier studies on reduced-fat cookies (Swanson and Carden 1999; Armbrister and Setser 1994).

Cookie fat contents also varied with formula ($p < 0.0001$) (Table IV-6). The 55% reduction levels with Stardri and Simplesse were the same in cookie fat content but lower than the Betatrim 35% and full-fat cookies. Betatrim 35% cookies contained significantly less fat than the full-fat cookies. Projected fat contents of 35%, 55%, and 55% for Betatrim, Stardri, and Simplesse cookies, respectively, were compared to the actual mean cookie fat contents stated in Table IV-5. Betatrim fat replacement was determined to reduce fat 28%, which is less than the projected 35%. Stardri and Simplesse cookies were determined to be 53 and 54% reduced in fat which equals the expected 55% reduction level.

Projected formula differences in the Betatrim cookies may have been a result of errors in ingredient weighing, errors in mixing and transfer of the creamed mass to the different mixing bowls, and differences in loss of fat during baking. The Soxhlet extraction method used for fat determination also has limitations. Bound lipids are not extracted (Min 1994). Although the 28% reduction for the Betatrim cookies did not match the projected 35% fat reduction, the required 25% reduction for "reduced fat" was still achieved. Stardri and Simplesse also met this legal definition and provided less than 3 g fat/cookie serving (FDA 2000).

Calories for each cookie treatment were estimated from mean fat, protein, and carbohydrate contents reported in Table IV-5; caloric values among the reduced-fat and -sugar cookies are reported in Appendix E. Manufacturer provided values of 2.0 and 2.1 kcal/g were used for Isomalt and Maltitol, respectively, to estimate carbohydrate calories. The full-fat/full-sugar cookies for all flours were approximately 98 kcal/cookie.

On average the 35% fat/65% sugar reduction combinations resulted in 18% caloric reduction per cookie. The 55% fat/65% sugar reduction combinations resulted

Table IV-6-Least-squares mean[ab] estimates and standard errors for moisture, fat, protein, and fat contents as affected by fat replacer in wire-cut cookies

	Moisture		Fat		Protein		Ash	
Fat replacer (%)				%				
Full fat	6.0a	0.27	18.6a	0.67	4.2b	0.07	1.2b	0.04
Betatrim (35)	8.6b	0.16	13.3b	0.58	4.3b	0.05	1.2b	0.02
Stardri (55)	10.2c	0.16	8.5c	0.58	4.3b	0.05	1.2b	0.02
Simplesse (55)	10.4c	0.15	8.8c	0.57	5.5a	0.05	1.4a	0.02

[a] Means across 3 flour protein levels and sugar/sugar replacer system.
[b] Mean estimates in columns followed by unlike letters are significantly different ($p < 0.0001$).

in 26% fewer calories than the full-fat/full-sugar cookies. To be considered "reduced-calorie", a 33 1/3% reduction in calories per serving must be met (FDA 2000). The reduced-fat and -sugar cookies in this study did not achieve this caloric reduction.

Water Activity

Flour protein influenced water activity ($p = 0.0091$). When flour protein content increased from 5.5 to 8.8%, cookie water activity significantly increased from 0.56 to 0.58. Water activity of the cookies made with the 7.3% protein flour was similar to both 5.5 and 8.8% protein flours. These findings suggest that when a flour has a higher water retention capacity, or absorptive properties, water activity will be increased. This could impact shelf-life of a product.

The interaction between FPRO X FATR was not significant for water activity. Fat replacer affected water activity ($p < 0.0001$), and results suggest that level of fat reduction was important. The full-fat cookies had a significantly lower water activity of 0.44. When Betatrim 35% fat replacement was incorporated, water activity increased to 0.59; the Stardri and Simplesse cookies at 55% fat reduction had the highest water activities of 0.59 and 0.60, respectively. These findings indicate that when moisture content increased in the cookies as fat replacement increased, water activity was higher. Similar results have been found (Swanson and Carden 1999). Sanchez and others (1995), however, did not find an increase in water activity with higher cookie moisture content.

In this study, cookies were formulated with polydextrose and polyol sugar replacers. These ingredients are considered to be non-hygroscopic (Olinger and Velasco 1996); however the effect of sugar replacer or the interactions with sugar replacement were not significant for cookie water activity in this experiment. Additional research is needed to address if water activity would be influenced over a specified time frame and if these ingredients extend cookie shelf-life.

Cookie Spread and Instrumental Hardness

The interactions among flour protein, fat replacer, and sugar replacer were not significant for cookie spread and hardness. Flour protein level affected cookie spread ($p < 0.0001$) but did not affect cookie hardness. Cookie spread significantly decreased from 10.9 to 9.8 and 8.4 for each respective increase in flour protein content. In general, all spread values were larger than those produced by the flours used in Part 1 and also greater than the desirable spread factor of 7.5-7.9 (Anonymous 2001). The differences between the 2 studies possibly reflects the variation in wheat source that was introduced with the new batch of the low-protein flour. Protein contents of the both batches of low-protein flour were similar (5.5%); however slight variation in protein quality may exist. Differences in the micro- and macro- methods used in Parts 1 and 2, respectively, may have also introduced mixing variations that possibly explain differences in cookie spread.

Fat replacer was significant for both cookie spread ($p < 0.0001$) and cookie hardness ($p < 0.0001$) (Table IV-7). Simplesse cookies were the smallest. The added protein this ingredient contributed may have resulted in earlier cookie set-time during baking. Cookie spread for the other fat replacers was similar to the full-fat cookies.

Stardri cookies were similar in cookie hardness to the full-fat cookies and both treatments were significantly harder than Betatrim and Simplesse cookies (Table IV-7). In the present study, Betatrim cookie spread was similar to the full-fat cookie spread but full-fat cookies were harder. As reported in Table IV-6, Betatrim cookies had higher moisture content than the full-fat cookies, which may contribute to the softer texture of Betatrim cookies; however moisture contents for Stardri and Simplesse cookies were also greater than the full-fat cookies, but only Simplesse cookies were softer than the full-fat. These results suggest that final cookie spread and texture is affected by fat replacer, but each fat replacer will affect water mobility in the cookie differently. This water mobility will ultimately affect cookie spread rate, cookie set-time, and texture.

Sugar replacement was also significant for cookie spread ($p < 0.0001$). Spread estimates were 10.4, 9.8, and 9.1 for Isomalt, Maltitol, and full-sugar cookies, respectively; all differed from each other. The mixing rate or time for the macro-method used in Part 2 may not have been sufficient to completely dissolve the sucrose present in the cookie dough. The less fluid doughs would spread less. In contrast, the high solubilities of the polyols and how shortening complexed with these ingredients may have contributed to a more fluid dough and faster spread rate.

Table IV-7–Least-squares mean[ab] estimates for cookie spread and hardness as a function of fat replacer for wire-cut cookies

Fat replacer (% fat reduction)	Cookie spread[c]		Cookie hardness (g)[d]	
Full fat	9.8	a	930	a
Betatrim (35)	9.8	a	560	b
Stardri (55)	10.3	a	864	a
Simplesse (55)	8.9	b	504	b

[a] Mean estimates across 3 flour protein levels and sugar/sugar replacer system.
[b] Mean estimates followed by unlike letters in columns are statistically different ($p<0.0001$); standard errors of the means were 0.35-0.44 and 105-116 for spread and hardness values, respectively.
[c] Cookie spread calculated as width (cm) of 4 cookies/thickness (cm) of 4 cookies per treatment; average of 4 width measurements and 2 thickness measurements reported.
[d] Cookie hardness evaluated with a texture analyzer (TA.TXT2 Texture Technologies, Scarsdale, NY) affixed with a TA-53 3-mm probe; hardness values are the average of 7 probes/cookie (1 center probe + 6 side probes equidistant from center probe) and 2 cookies/treatment.

Color Evaluation

Figure IV-1 illustrates the effect of FPRO X FATR ($p = 0.0039$) on L*, which is a measure of lightness with 0=black and 100=white. Full-fat cookies became lighter when flour protein increased to 7.3%. This variation in L* value was not seen with the fat replacers when flour protein increased, except Simplesse cookies were darker when flour protein increased from 7.3 to 8.8%. In the low-protein flour, Simplesse and full-fat cookies were similar in L* and darker than cookies made with the carbohydrate-based fat replacers. At 7.3% flour protein, full-fat, Betatrim, and Stardri cookies were similar; Simplesse cookies were darker than full-fat cookies but similar to Stardri cookies. In the highest protein flour, full-fat and Betatrim cookies were similar in lightness and lighter than Stardri and Simplesse cookies.

Figure IV-2 shows the significant interaction between FPRO X FATR on the Minolta a* value ($p = 0.0383$), which is a measure of the degree of redness (+) or greenness (-). In the low-protein flour, Simplesse cookies were similar in redness to the full-fat cookies; however as flour protein increased, Simplesse cookies were significantly higher in redness than the full-fat cookies. Increased carbonyl-amine browning may occur with the protein-based fat replacer. This may explain the higher a* and lower L* values produced by this fat replacer. Stardri and full-fat cookies were similar in a*; Betatrim cookies were significantly lower in a* than full-fat cookies when combined with the low-protein flour. When flour protein increased to 7.3% and 8.8%, a* values for Stardri and Betatrim were similar to the full-fat cookies.

Minolta b* and hue angle, which is calculated from a* and b*, were significantly affected by fat replacer (Table IV-8). Hue angle has been reported to be a better indicator of human color perception because a* and b* values are given a value relative

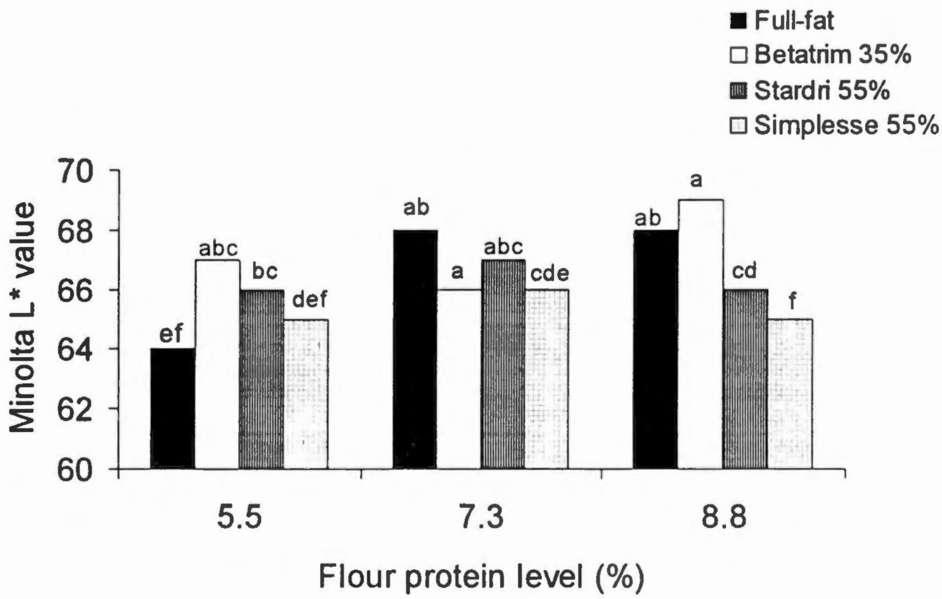

Figure IV-1–Effect of flour protein level and fat replacer on Minolta L* values (0=black, 100=white) for wire-cut cookies (LS mean estimates across sugar/sugar replacer system; bars with unlike letters are significantly different p = 0.0039).

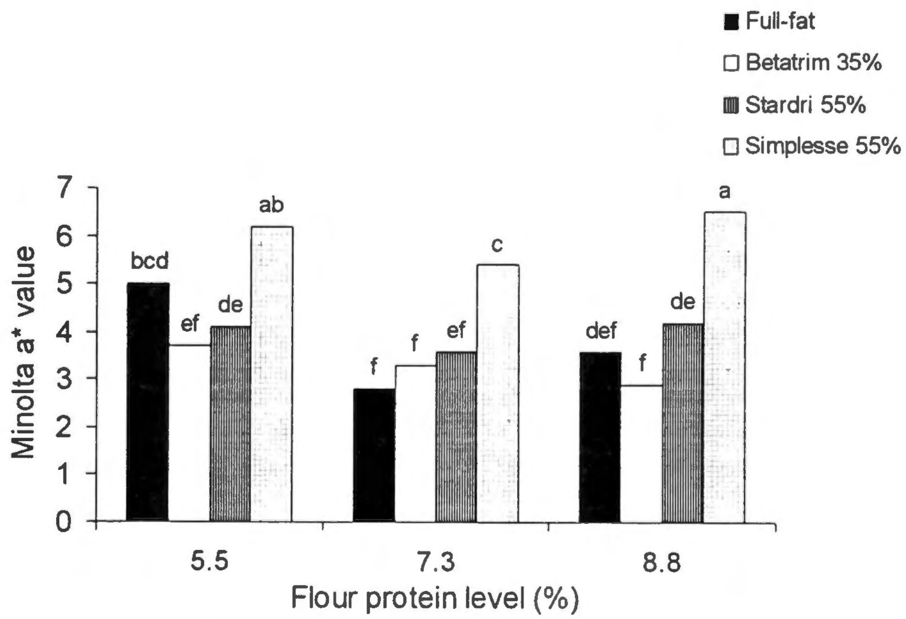

Figure IV-2– Effect of flour protein level and fat replacer on Minolta a* values (redness) of wire-cut cookies (LS mean estimates across sugar/sugar replacer system; bars with unlike letters are significantly different, p = 0.0383).

to how a human would evaluate the color of an object (Shewfelt undated). As the hue angle approaches 90°, increased yellowness would be perceived. Therefore, even when larger b* values are present, a product can still be seen as less yellow. This is the case with Simplesse cookies which had significantly higher b* values but hue angle was significantly less than the other fat systems. The full-fat, Betatrim, and Stardri cookies on the other hand would be seen as more yellow although the b* values were less. Hue angle and L* values were similar for each of the fat systems. When cookies were lighter, hue angle or yellowness was also higher. The opposite was true for a* value. As redness increased in the cookies, hue angle and L* decreased.

L*, a* and b* values were significantly affected by sugar replacer; however hue angle was not (Table IV-9). Maltitol cookies were most yellow, followed by Isomalt, then full-sugar. Maltitol cookies were also more red and were significantly lighter. Isomalt cookies and full-sugar cookies were similar in redness (a*) and lightness (L*). Neither polyol sugar replacer has aldehyde groups that will participate in carbonyl-amine reactions (Moskowitz 1991; Strater and Irwin 1991); therefore differences in color from the full-sugar cookies were not expected. The large cookie spreads produced by

Table IV-8–Least-squares mean[ab] estimates and standard errors for Minolta b* and hue angle values[c] as a function of fat replacer for wire-cut cookies

Fat treatment (%)	b*			Hue angle[d]		
Full fat (0)	30	c	0.51	83	ab	1.2
Betatrim (35)	31	bc	0.42	84	a	1.0
Stardri (55)	31	b	0.42	83	b	1.0
Simplesse (55)	33	a	0.42	80	c	1.0

[a] Mean estimates across 3 flour protein levels and sugar/sugar replacer system.
[b] Mean estimates followed by unlike letters in columns are statistically different ($p < 0.0001$).
[c] Colorimetric analysis conducted with a Minolta CM 508 tristimulus color analyzer, illuminant C, 10° and interpretation similar to Hunter L a and b system.
[d] calculated by $\tan^{-1} b^*/a^*$.

Maltitol may enhance rate of surface drying, resulting in larger a* and b* values. Hue angle was not affected by sugar replacer; therefore the higher b* value may not be a true indicator of cookie yellowness that would be visually perceived.

Sensory Evaluation

A trained sensory panel found differences in several cookie attributes. Appearance attributes included baked color and internal cell size. Surface roughness, hardness, fracturability, moistness, and molar packing were assessed to measure textural differences. Cookies were also evaluated for flavor differences in almond flavor, sweetness, browned flavor, and aftertaste.

Cookie Appearance

FPRO X FATR ($p = 0.0045$) was significant for perceived baked color of the cookies (Figure IV-3). Except for Betatrim, full-fat and reduced-fat cookies were similar in baked color when the higher protein flours were used. The full-fat/low-protein flour

Table IV-9–Least-squares mean[ab] estimates and standard errors for Minolta L*, a*, and b* values[c] as a function of sugar replacer for wire-cut cookies

Sugar treatment (% sugar reduction)	L*		a*		b*	
Full sugar (0)	67 a	0.91	4.2 a	0.64	30 a	0.41
Isomalt (65)	66 a	0.92	4.1 a	0.65	32 b	0.42
Maltitol (65)	66 b	0.92	5.0 b	0.65	33 c	0.43

[a] Mean estimates across 3 flour protein levels and fat/fat replacer system.

[b] Mean estimates followed by unlike letters are statistically different ($p = 0.0151$(L*); $p = 0.0059$ (a*); $p < 0.0001$(b*)); hue angle not significant for sugar replacer.

[c] Colorimetric analysis conducted with a Minolta CM 508 tristimulus color analyzer (illuminant C, 10°); interpretation similar to Hunter L a and b system.

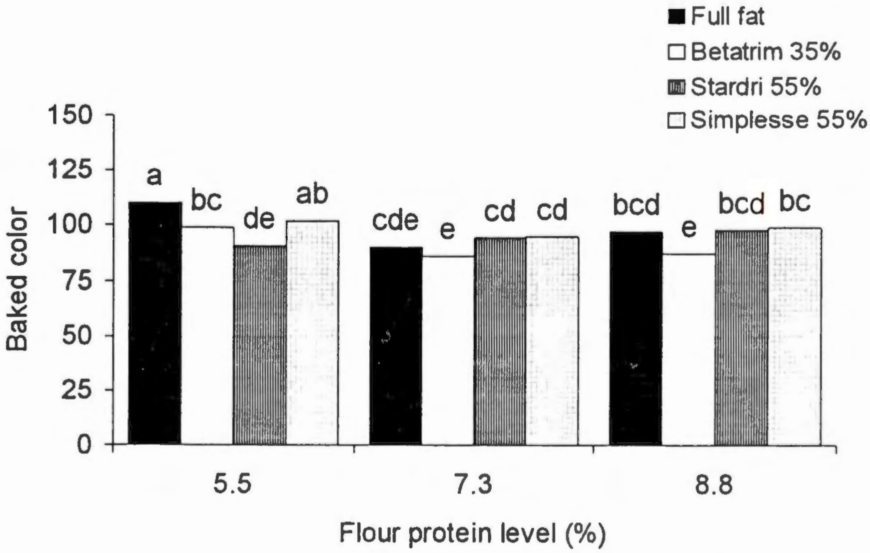

Figure IV-3–Effect of flour protein level and fat replacer on perception of wire-cut cookie baked color as rated by 12 panelists with 0 = very pale to 150 = very dark (LS mean estimates across sugar/sugar replacer system; bars with unlike letters are significantly different, p = 0.0045).

was perceived as darker than all flour/fat combinations except for the Simplesse/low-protein flour. Compared to the full-fat cookies, baked color decreased for Betatrim and Stardri cookies in the low-protein flour; however, these carbohydrate-based replacers were not different in baked color from the full-fat cookies in the higher protein flours.

These differences in perceived baked color may be attributable to water retentive properties of the flours, cookie spread rate and set-time, and final cookie moisture properties. Full-fat/low-protein flour cookies likely had a faster spread rate, delayed cookie set-time and low cookie moisture; therefore interactions between flour proteins and sugars may have been enhanced. The added protein from Simplesse combined with the low-protein flour, may have been sufficient to produce similar surface browning as the full-fat, although moisture content was increased with fat replacement. The water added with the carbohydrate-based fat replacers in the low-protein flour did not permit these browning reactions to occur to the same degree.

FATR X SUGR also affected the attribute of baked color ($p = 0.0075$) (Figure IV-4). Isomalt cookies with any fat/fat replacer system produced cookies similar to the control. Maltitol/Betatrim cookies were rated lighter than the control but were similar to the full-sugar/Betatrim cookies. These results suggest that sugar replacer was more influential on the baked color when Betatrim was used for fat replacement. Stardri on the other hand produced cookies with a consistent baked color rating regardless of sugar/sugar replacer system. The polyols produced cookies that were similar in baked color when Simplesse was used, but only full-sugar/Simplesse cookie baked color was similar to the control cookie baked color.

Internal cookie cell size was rated using the pictorial reference (Appendix E). The interactions among flour protein, fat replacer, and sugar replacer were not

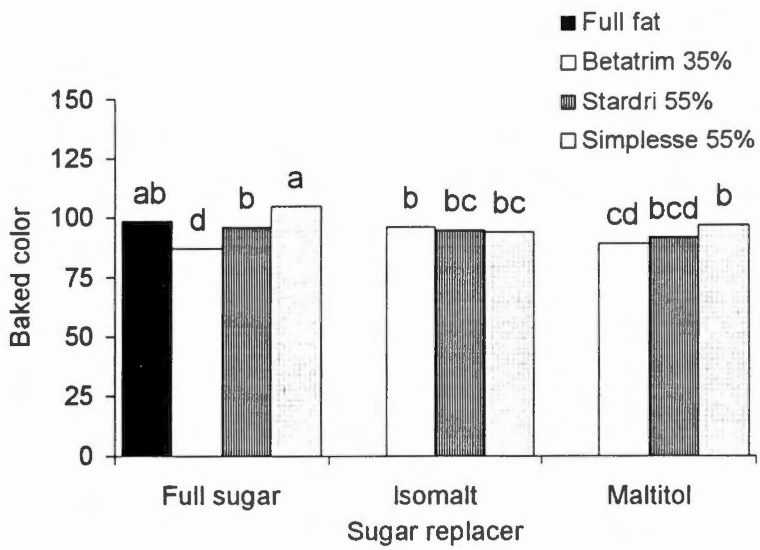

Figure IV-4–Effect of fat replacer and sugar replacer on perception of wire-cut cookie baked color rated by 12 panelists with 0 = very pale to 150 = very dark (LS mean estimates across 3 flour protein levels; bars with unlike letters are significantly different, p = 0.0075).

significant for this attribute; however the cell size significantly increased with the lower protein flours (Table IV-10). The lower protein flours were more ideal in creating a layered cookie matrix with discernable gas pockets between the layers. When the higher protein flours were used, the cookie matrix became more dense and compact without the desirable layering. The different fat systems did not affect cell size, indicating that each fat replacer would have the capability to produce a crumb grain similar to the full-fat cookies. Sugar replacer was also significant for crumb cell size (Table IV-11). The full-sugar cookies had larger cells than the reduced-sugar cookies which were similar. This suggests that the bulking characteristics of sucrose may be replaced with a polyol sugar replacer, but the desirable layer and gas pocket formation is limited. This may be attributed to how polyols and sucrose interact with fat in the cookie system.

Cookie Texture

The interaction of flour protein and fat replacer was significant for cookie surface roughness and moistness. Surface roughness, defined as the presence of bumps or particles when lips are passed over the top of the cookie surface, was significantly higher in the 5.5% protein flour and full-fat combination than all other flour/fat treatments (Figure IV-5). For the full-fat treatment, cookie surface was rated smoother when higher protein flours were used; Betatrim cookies were similar in surface roughness in the higher protein flours. For all flours, cookie surface was perceived as smoother with the 55% fat reduction level with Stardri or Simplesse compared to Betatrim or full-fat cookies. This suggests that, when a low protein flour is used, the uneven surface grain that the full-fat cookies exhibited will be diminished

Table IV-10–Least-squares mean[ab] estimates for sensory attributes as a function of flour protein level for wire-cut cookies

		Flour protein level (%)		
Cookie attribute[c]	p value	5.5	7.3	8.8
Cell size	<0.0001	65a	61b	57c
Fracturability	0.0005	50a	46b	43b
Molar packing	0.0009	79a	75b	73b
Almond flavor	0.0017	79a	73b	69b
Sweetness	0.0003	81a	74b	71b
Browned flavor	0.0150	75a	71b	71b

[a] Mean estimates across fat/fat replacer and sugar/sugar replacer systems.
[b] Mean estimates in rows followed by different letters are statistically different.
[c] Each attribute rated on an unstructured line scale of 0-150 with the following anchors: very small air cells-very large air cells for cell size; crumbly-brittle for fracturability; none-excessive packing for molar packing; none-very intense for almond flavor, sweetness, browned flavor, and aftertaste.

Table IV-11–Least-squares mean[ab] estimates for sensory attributes as a function of sugar replacer for wire-cut cookies

		Sugar replacer (%)		
Cookie attribute[c]	p value	Full sugar	Isomalt (65)	Maltitol (65)
Cell size	<0.0001	64a	59b	59b
Surface roughness	<0.0001	60a	66b	56c
Fracturability	0.0012	45a	49b	45a
Molar packing	0.0017	70a	81b	78b
Aftertaste	0.0018	53a	61b	62b

[a] Mean estimates across flour protein level and fat/fat replacer system.
[b] Mean estimates in rows followed by different letters are statistically different.
[c] Each attribute rated on an unstructured line scale of 0-150 with the following anchors: very small air cells-very large air cells for cell size; smooth-rough for surface roughness; crumbly-brittle for fracturability; none-excessive packing for molar packing; none-very intense for aftertaste.

when fat replacers are used. Armbrister and Setser (1994) also found that fat replacers generally resulted in smoother cookie surface.

Surface roughness was originally selected as an attribute because in Part 1, cookie surface was observed to vary with sugar replacers. In the present study, the Isomalt cookies were significantly more rough on the surface than the full-sugar or Maltitol cookies (Table IV-11) which may be attributed to the presence of white crystals observed on the surface of the Isomalt cookies. The presence of these white crystals has been reported by other researchers, and the number and size of the crystals has been shown to increase when product moisture content increases (Setser and Racette 1992). This was the case with the reduced-calorie formulations in this study. Setser and Racette (1992) also reported that Isomalt in short crust dough products such as cookies will harden after processing and appropriate formula water concentrations must be determined to minimize this effect.

As previously discussed, cookies varied in moisture content when fat replacers were added (Table IV-6). Significant differences in sensory cookie moistness were found for the interaction of FPRO X FATR ($p = 0.0007$) (Figure IV-6). In most cases full-fat cookies within a flour protein level were considered more dry than their reduced-fat counterparts (Figure IV-6). These results indicate that the panelists were able to detect differences in the flour water retentive properties as well as the higher moisture contents associated with fat replacement. Simplesse replacement produced the moistest cookies in the lower protein flours, but when flour protein was increased to 8.8%, Stardri and Simplesse were similar in perceived moistness. When the higher protein flours were used, Stardri and Betatrim cookies were similar in perceived moistness. Betatrim and full-fat were also similar in the 8.8% flour. These results

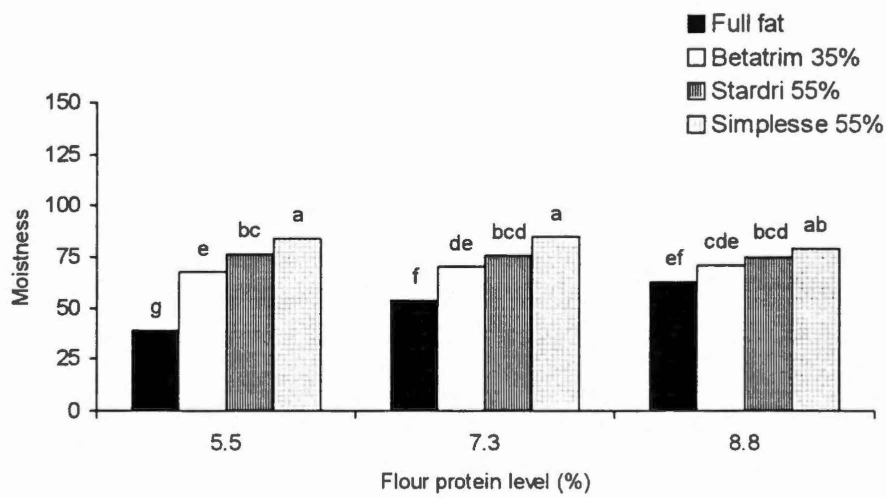

Fig. IV-6–Effect of flour protein level and fat replacer on perception of wire-cut cookie moistness rated by 12 panelists with 0 = dry to 150 = moist (LS mean estimates across sugar/sugar replacer system; bars with unlike letters are statistically different, p=0.0007).

indicated that the higher water retentive properties in the higher protein flours increased perceived cookie moistness in the full-fat and Betatrim cookies although actual cookie moisture content was lower than the cookies with 55% fat reduction. A shortbread cookie was used as the mid-point reference for moistness on the 0-150 scale. Stardri cookies for all flours and Simplesse with the 8.8% flour had moistness ratings similar to this reference.

FATR X SUGR affected perceived cookie moistness ($p = 0.0225$) (Figure IV-7). Simplesse combined with either polyol was perceived as the moistest and the control fat/sugar cookie was driest. Betatrim with full-sugar or Maltitol produced cookies that were similar in perceived moistness; however Betatrim/Isomalt was significantly more moist than the Betatrim/full-sugar. Stardri cookies did not vary in perceived moistness among the different sugar systems.

Cookie hardness was affected by FATR X SUGR ($p = 0.0251$)(Figure IV-8). Full-fat/full-sugar cookies were rated similar to the shortbread cookie reference for hardness (75). The full-fat/full-sugar cookie was harder than the Betatrim and Simplesse cookies when combined with any sugar system. Stardri cookies with either sugar or Maltitol, were equal to the control in cookie hardness. Stardri/Isomalt cookies were softer than the control, but similar in hardness to the Stardri/full-sugar or Maltitol cookies. Simplesse with sugar or Maltitol, produced cookies significantly softer than the other treatments and the control.

Perceived hardness as a function of flour protein and fat replacer approached a significant effect ($p = 0.0510$). Hardness followed a trend opposite to that of moistness. Less moist cookies tended to be harder. Hardness for 5.5% protein flour/full-fat cookies were rated between a shortbread (75) and a gingersnap (150) at 91. Hardness

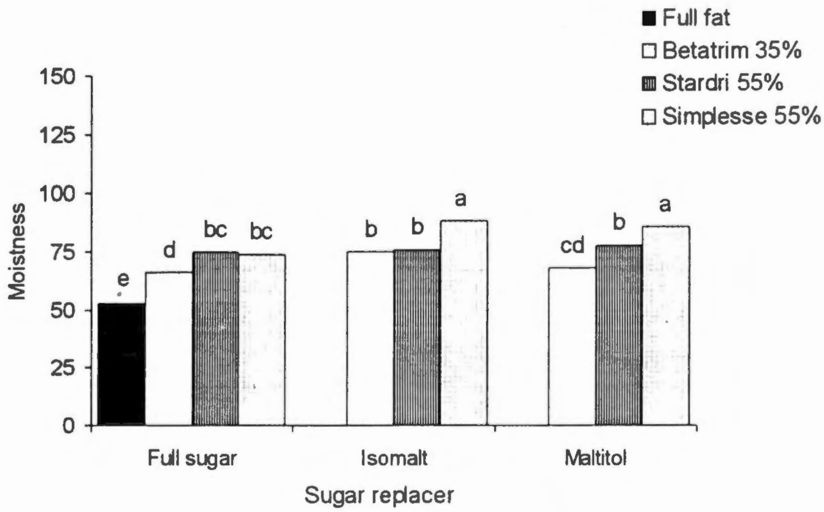

Figure IV-7–Effect of fat replacer and sugar replacer on perception of wire-cut cookie moistness rated by 12 panelists with 0 = dry 150 = moist (LS mean estimates across 3 flour protein levels; bars with unlike letters are statistically different, p=0.0025).

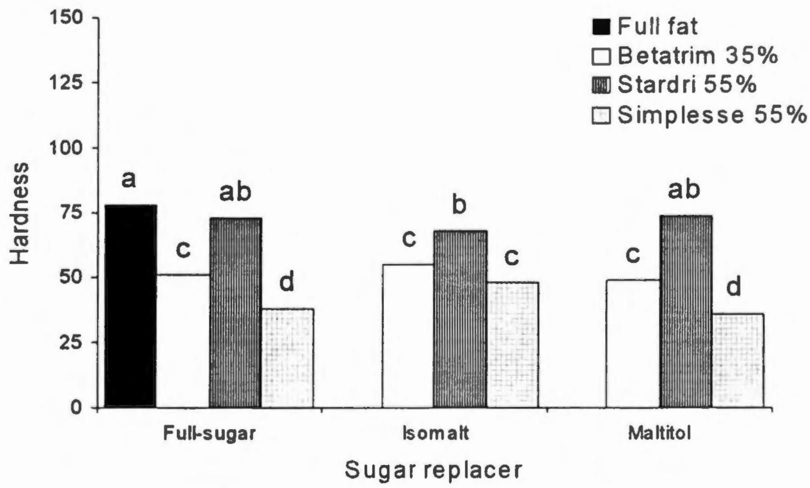

Figure IV-8– Effect of fat replacer and sugar replacer on perception of wire-cut cookie hardness rated by 12 panelists with 0 = very soft and 150 = very hard (LS mean estimates across 3 flour protein levels; bars with unlike letters are statistically different (p=0.0251).

decreased as flour protein increased. It was also observed that flour protein level did not cause differences in hardness for Stardri cookies. When flour protein increased from 5.5 to 8.8%, Betatrim cookies became softer which coincides with the increasing water retentive properties of the high-protein flours.

Cookie fracturability, or the force with which the sample shatters or crumbles, was different as a function of the individual effects of flour protein, fat replacer, and sugar replacer. The lower protein flour produced the most fracturable cookies and the higher protein flours were similar in fracturability (Table IV-10). Stardri and full-fat cookies were similar in fracturability; Betatrim and Simplesse cookies were similar in perceived fracturability (Table IV-12). Maltitol and full-sugar cookies were similar and less fracturable than Isomalt cookies (Table IV-11). When compared to the reference products for fracturability, all treatments produced cookies that were rated less brittle than the graham cracker reference (70).

Table IV-12–Least-squares mean[ab] estimates for sensory attributes as a function of fat replacer for wire-cut cookies

		Fat treatment (% fat reduction)			
Cookie attribute[c]	p value	Full fat	Betatrim (35)	Stardri (55)	Simplesse (55)
Cell size	0.0014	58a	61a	61a	62a
Fracturability	<0.0001	55a	39b	59a	37b
Molar packing	<0.0001	60c	72b	79a	81a
Almond flavor	0.0271	64c	78a	74ab	73b
Browned flavor	0.0174	80a	71b	73b	71b

[a] Mean estimates across 3 flour protein levels and sugar/sugar replacer systems.
[b] Mean estimates in rows followed by different letters are statistically different.
[c] Each attribute rated on an unstructured line scale of 0-150 with the following anchors: very small air cells-very large air cells for cell size; crumbly-brittle for fracturability; none-excessive packing for molar packing; none-very intense for almond flavor, browned flavor.

Molar packing was defined as the amount of food material left in and around the molar teeth at the end of chewing. Variation in degree of molar packing was affected by flour protein level, fat replacer, and sugar replacer. As reported in Table IV-10, the 5.5% protein flour produced cookies more likely to tooth pack; the higher protein flours were not significantly different for molar packing. Unlike the results found by Armbrister and Sester (1994), in which no differences in molar packing were found between fat replacers and control fat in chocolate chip cookies, the present study indicates that full-fat cookies were significantly lower in molar packing than cookies made with fat replacers (Table IV-12). The carbohydrate-based replacers, Betatrim and Stardri, were similar in molar packing; Simplesse cookies were perceived to have a higher degree of molar packing than all other treatments. Degree of molar packing was also attributable to sugar replacement (Table IV-11). Full-sugar cookies were significantly less likely to tooth pack than cookies made with polyol sugar replacers. Isomalt and Maltitol cookies were similar in tooth packing. Variation in molar packing as a result of differences in either flour protein level, fat replacer, or sugar replacer may have been attributable to how the different ingredients absorbed saliva in the mouth during mastication. Further research is needed to address the degree of moisture absorption of the cookie sample during chewing to investigate if the different ingredients would affect this attribute and molar packing.

Cookie Flavor

Some effects were important to almond flavor and aftertaste. Cookies were flavored with a natural almond flavoring. Perceived almond flavor intensity was significant for the effects of flour protein and fat replacer. The 5.5% flour was perceived to have the most intense almond flavor intensity and the higher protein flours did not differ in almond flavor intensity (Table IV-10). Fat replacer also was shown to affect perceived almond flavor. The carbohydrate-based fat replacers were similar in cookie almond flavor; Simplesse cookies were similar to Stardri cookies in perceived almond flavor (Table IV-12). Full-fat cookies were the least intense in almond flavor. These results suggest that the increased shortening present in the full-fat cookies may coat the flavor molecules. The type of fat replacer and the additional water added to the fat system contributed to differences in perceived intensity of almond flavor in the reduced-fat cookies.

Compared to the carbohydrate-based fat replacer, Simplesse was closest in almond flavor intensity to the full-fat. Binding of flavor compounds by proteins can result in the suppression of the primary flavoring impact (Rogacheva and others 1999). Hansen and Heins (1992) reported a drop in benzaldehyde-flavor sensory intensity, the primary compound associated with cherry or almond flavor notes, when whey protein concentrate (WPC) was increased from 0-0.5% in solution with the flavor compound. Both authors indicated β-lactoglobulin was responsible for flavor binding between the WPC and the aldehyde structure. Simplesse cookies were however, similar to Stardri cookies for almond flavor intensity. The similar level of fat reduction, and therefore, similar amounts of shortening present in each formula, may explain the similarities.

Perception of almond flavor intensity was similar for the Betatrim and Stardri cookies. The water-soluble nature of these carbohydrate-based fat replacers may permit more flavor release within the mouth during chewing. Betatrim fat replacer is derived from oats, which may have contributed a more perceived "nutty" flavor. Although the full-fat cookies were perceived to have less intense almond flavor, sensory testing that would address the level of almond flavor intensity that is most preferred and the overall flavor balance is warranted.

Flour was shown to affect sweetness and browned flavor. Cookies made with the 5.5% flour protein were perceived to be sweeter and have more intense browned flavor than the higher protein flours (Table IV-10); the 7.3 and 8.8% protein flours were similar in perceived sweetness and browned flavor. Decreased water retention of the low-protein flour may permit increased surface browning as more water evaporated during baking. Aftertaste was significantly higher in the sugar-replaced cookies compared to the full-sugar cookies ($p=0.0018$) (Table IV-11). Both polyols had Ace-K added to increase sweetness, and a chemical taste has been associated with this high intensity sweetener (Giese 1993).

Correlation of Sensory and Instrumental Values

Color values of L*, a*, b*, and hue angle were correlated with baked color. Cookie lightness was the only attribute that was significantly correlated with perceived baked color, but a moderate to weak negative correlation existed ($r = -0.42$; $p = 0.0225$). Cookies with lower L* values were perceived as more intense in baked color.

Sensory attributes of cookie hardness, fracturability, moistness, and molar packing were correlated with instrumental cookie hardness values. A moderate positive correlation ($r = 0.69$, $p < 0.0001$) was found for instrumental hardness and sensory hardness ratings of the cookies indicating the probing method was not a strong predictor of the sensory textural values. This was also true for fracturability ($r = 0.69$, $p < 0.0001$). Cookie moistness and molar packing was negatively correlated with instrumental hardness ($r = -0.69$, $p < 0.0001$ and $r = -0.30$, $p = 0.0002$, respectively).

Correlation coefficients of 0.9-1.0 have been reported to indicate the instrumental technique is a good predictor of sensory (Bourne 1982); however this study did not find this relationship. Panelists may require additional training and familiarity of the reference products. Selection and development of product-specific references in order to narrow the intensity scale of each attribute and comparisons of other instrumental methods with sensory is warranted.

Summary, Conclusions, and Implications

The primary objective of this study was to investigate the roles of flour protein content, fat replacer, and sugar replacer on sensory perception of 11 different cookie attributes. Selection of the different ingredient combinations was based on the previous study (Part 1). Betatrim at 35%, Stardri and Simplesse at 55%, and a full-fat formula were compared. Two polyols, Isomalt and Maltitol, replaced sugar at 65% and a full-sugar treatment were used with the full-fat treatment.

Nutritional analysis of the cookies confirmed that reduced-fat cookies can be successfully achieved with fat replacers available to industry. Cookie fat content was appropriately decreased by all fat replacers to meet the required 25% fat reduction; however caloric reduction is more difficult. Fat reduction would need to be increased to exceed the 33 1/3 % reduction in calories/serving requirement. The addition of gums and blends with the tested ingredients should be investigated for this purpose.

The results of this study, as with Part 1, indicate that flour water retention increased when the flour protein content increased. Besides flour protein content, investigation of percentage starch damage, which has been correlated with reduced cookie spread, is warranted. The higher protein flours contained a 4th break flour which may possess a higher starch damage. Besides flours similar to the test flours, additional flours produced from various wheat sources and/or millers must be studied to confirm the relationship of flour protein and other attributes with cookie quality. Sensory evaluation may also be effective in discerning differences in flour moisture properties as indicated by the significant effects of flour protein and fat replacer for perception of cookie moistness.

The interactions among flour protein level, fat replacer, and sugar replacers suggest that the physico-chemical changes that occur as these ingredients are interchanged impact sensory attributes of cookie baked color, cookie hardness, cookie moistness, and surface roughness. Not only does flour protein level influence these attributes, but also type of fat replacer and the water holding properties are important to the changes that occurred. Instrumentation such as differential scanning calorimetry may be valuable in the study of how these ingredients and flours of different quality will ultimately alter cookie spread rate and set-time. Better understanding of how these processes are controlled and how cookie texture may be altered is needed. Functional properties of fat and sugar replacers require additional study as well, with emphasis on their interaction. Two polyols were currently examined; however other sugar replacers, such as polydextrose, lactiltol, and maltodextrins, are commonly used in bakery applications (Setser and Racette 1992). Sugar replacement with the polyols may enhance shelf-life but fat replacers which require additional water for hydration off-set this benefit. Finding appropriate fat and sugar combinations to maximize the water activity and mobility within the cookie matrix would be advantageous.

Sensory perception of cookie hardness and moistness was impacted by the interaction of fat replacer and sugar replacer. Harder cookies were generally drier. In most cases full-fat cookies were harder and drier and Simplesse cookies were softer than the other cookies. Stardri fat replacement generally produced cookies of similar hardness and moistness to the full-fat or was consistent in these variables when the sugar system was altered. Differences in the perception of sensory attributes of baked color, cell size, fracturability, molar packing, and several flavor attributes were attributed to the main effects of flour, fat, and sugar. Simplesse cookies were perceived to be darker and had a significantly lower L and hue angle indicating that the protein-based fat replacer may participate in more carbonyl-amine reactions. Ultimately, research is needed to find ideal reduced-calorie ingredient combinations that will result in the best cookie appearance, texture, and flavor attributes.

The attributes selected for the present study were effective as an initial step in sensory evaluation of the wire-cut cookie. However, textural and appearance attributes were generally more sensitive to the interactions of the test variables. This suggests that the attribute list could be shortened; ultimately less time would be needed for sensory evaluation. A moderate relationship between instrumental cookie hardness and textural attributes exists. Further work is needed in selecting/designing the most appropriate instrumental method for cookie texture assessment. Product-specific references could be developed to narrow each intensity scale, and procedures for training of panelists should be standardized. In order to adequately optimize cookie formulas as well as other bakery products for fat and sugar reduction, affective comparisons should be also be made.

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APPENDICES

APPENDIX A

TX.TXT2 Texture Analyzer Settings and Cookie Probing Guide

TA.TXT2 Texture Analyzer Settings[a]

Select settings (F4)	
Mode	Measure force in compression
Force units	Grams
Distance format	mm
Pre-test speed	6.0 (0.1-10.0 mm/s)
Test speed	5.0 (0.1-10 mm/s)
Post-test speed	6.0 (0.1-10 mm/s)
Distance	30 (0.1-999.9 mm)
Automatic trigger type	20 (1-25000g)
Select Method (F3)	
Graph type	Force vs. time
Auto scaling	on
Peak confirmation	off
Force threshold	20 (5-25000g)
Acquisition rate	200 pps
Force units	Grams
Contact area	1.0 (0.1-9999 mm^2)
Contact force	5.0 (0.1-5000g)

[a] TA-XT1 Software version 3.12 (Texture Technologies, Scarsdale, NY).

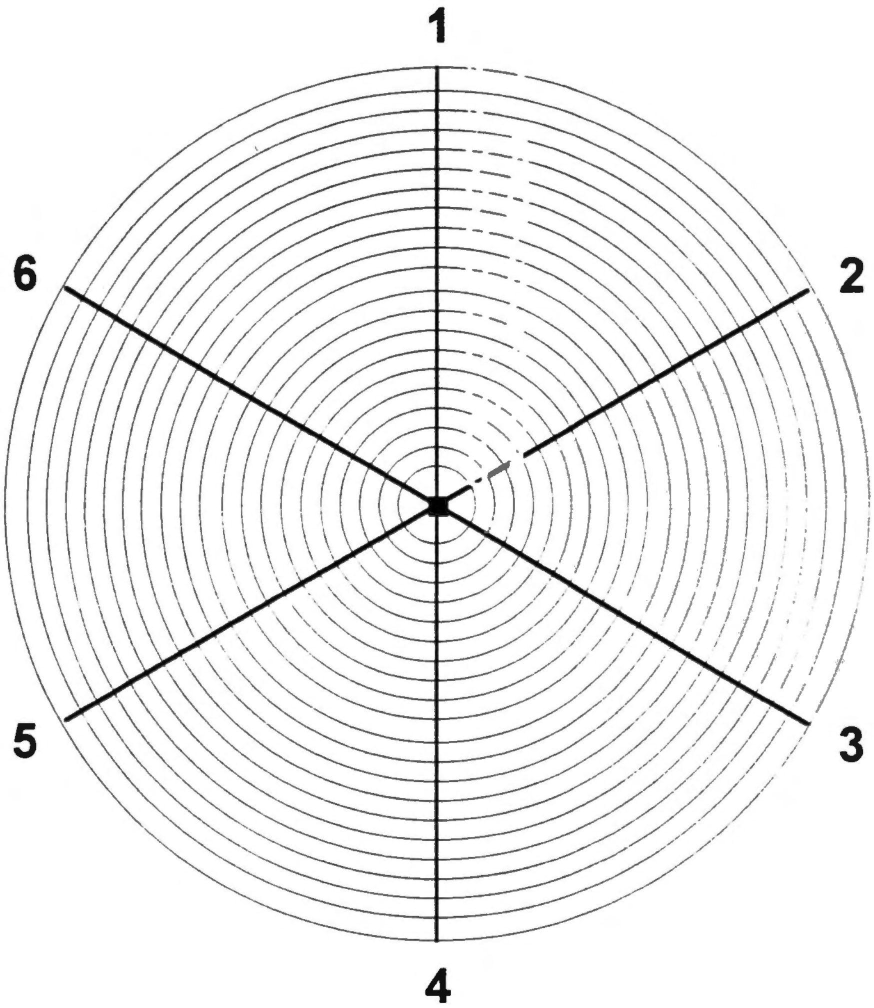


Figure A-1--Cookie probing guide.

APPENDIX B

SAS Programs for Analysis of Data

1. Cookie spread data for part 1

```
proc sort data = spread; by order; run;
proc sort data = codes; by order; run;
data finsprd;
merge spread codes; by order;
if trt = . then delete;
proc sort; by trt; run;
proc print; var order day  rep trt  fatR  fatL sugR sugL fpro width thick spread; run;
proc mixed data = finsprd;
class day rep fatR fatL sugR sugL fpro ;
model spread = fatR*fatL | sugarR*sugL |fpro/ outp=rrr;
random rep day(rep) day*fatR*fatL*sugR*sugL*fpro(rep);
lsmeans fatR*fat|sugarR*sugar|protein/pdiff;
ods output lsmeans=mmm diffs=ppp;
ods listing exclude lsmeans diffs;
run;
%include 'a:\pdmix800.sas';
%pdmix800 (ppp,mmm);
%include 'a:\lsdvalue.sas';
%lsdvalue(ppp);
proc univariate data=rrr plot normal;
var resid;
run;
```

2. Cookie hardness data for part 1

```
proc sort data = force; by order; run;
proc sort data = codes; by order; run;
data finforce;
merge force codes; by order;
proc means data=finforce noprint;
class fatR fatL sugR sugL fpro;
var force;
output out=stats mean=;
run;
data select;
set stats;
if _type_=31;
proc print data=select; run;
proc sort; by trt; run;
proc print; var order day rep trt fatR FatL SugR SugL fpro cookie force; run;
proc mixed data = finforce;
class day rep fatR fatL sugR sugL fpro;
model force = fatR*fatL | sugR*sugL | fpro/ outp=rrr;
random rep day(rep) day*fatR*fatL*sugarR*sugL*fpro(rep) ;
lsmeans fatR*fatL|sugR*sugL|fpro/pdiff;
ods output lsmeans=mmm diffs=ppp;
```

```
ods listing exclude lsmeans diffs;
run;
%include 'a:\pdmix800.sas';
%pdmix800 (ppp,mmm);
%include 'a:\lsdvalue.sas';
%lsdvalue(ppp);
proc univariate data=rrr plot normal;
var resid;
run;
```

3. Flour characteristics data for parts 1 and 2

```
proc means; run;
proc sort; by flour; run;
proc glm; class flour; model ash pro moist awrc ph peakht time develop bkdwn = flour;
lsmeans flour/pdiff;
run;
```

4. Proximate analysis and water activity data for part 2

```
proc mixed data = proxanal;
class fpro fatR sugR rep;
model ash* = fproR | fatR | sugR | outp=rrr;
random rep fpro*fatR*sugR (rep);
lsmeans fpro | fatR | sugR /pdiff bylevel om;
ods output lsmeans=mmm diffs=ppp;
ods listing exclude lsmeans diffs;
run;
%include 'a:\pdmix800.sas';
%include 'a:\lsdvalue.sas';
%lsdvalue (ppp);
proc univariate data=rrr plot normal;
var resid;
run;
```

*dependent variable changed to moisture, protein, fat, and Aw

5. Cookie spread data for part 2

```
proc mixed data = meanspread;
class rep day fpro fatR sugR;
model spread = fpro | fatR | sugR / outp=rrr;
random rep day(rep) day*fpro*fatR*sugR(rep);
lsmeans fpro | fatR | sugR /pdiff bylevel om;
ods output lsmeans=mmm diffs=ppp;
ods listing exclude lsmeans diffs;
```

```
run;
%include 'a:\pdmix800.sas';
%pdmix800 (ppp,mmm);
%include 'a:\lsdvalue.sas';
%lsdvalue(ppp);
proc univariate data=rrr plot normal;
var resid;
run;
proc print; run;
```

6. Cookie hardness data for part 2

```
proc mixed data = textphase2;
class rep day fpro fatR sugR;
model hard  = fpro | fatR | sugR / outp=rrr;
random rep day(rep) day*fpro*fatR*sugR(rep);
lsmeans flour | fat | sug /pdiff bylevel om;
ods output lsmeans=mmm diffs=ppp;
ods listing exclude lsmeans diffs;
run;
%include 'a:\pdmix800.sas';
%pdmix800 (ppp,mmm);
%include 'a:\lsdvalue.sas';
%lsdvalue(ppp);
proc univariate data=rrr plot normal;
var resid;
run;
proc print; run;
```

7. Cookie color data for part 2

```
proc means; var hue L a b; by code;
run;
proc mixed data = colordiffs;
class day fpro fatR sugR rep;
model L* = fpro | fatR | sugR / outp=rrr;
random rep day(rep) day*flour*fat*sug(rep);
lsmeans fpro | fatR | sugR /pdiff bylevel om;
ods output lsmeans=mmm diffs=ppp;
ods listing exclude lsmeans diffs;
run;
%include 'a:\pdmix800.sas';
%pdmix800 (ppp,mmm);
%include 'a:\lsdvalue.sas';
%lsdvalue(ppp);
```

```
proc univariate data=rrr plot normal;
var resid;  run;
proc print; run;
```

* dependent variable changed to a*, b*, and hue

8. Sensory data for part 2

```
proc mixed data = sensory;
class judge rep day fpro fatR  sugR ;
model baked color* = fpro | fatR | sugR / outp=rrr;
random judge rep day(rep) judge*day(rep) judge*day*fpro*fatR*sugR(rep);
lsmeans fpro | fatR | sugR /pdiff bylevel om;
ods output lsmeans=mmm diffs=ppp;
ods listing exclude lsmeans diffs;
run;
%include 'a:\pdmix800.sas';
%pdmix800 (ppp,mmm);
%include 'a:\lsdvalue.sas';
%lsdvalue(ppp);
proc univariate data=rrr plot normal;
var resid;
run;
proc print; run;
```

*this dependent variable would change: (cell size, surface, hardness, fracture, moist, molar, almond, sweet, bflavor, or aftertaste)

APPENDIX C

Tests of Fixed Effects

Tests of Fixed Effects

PART 1

Source	Num DF	Den DF	Type III F	Pr>F
Cookie spread with sucralose				
Flour Protein	3	241	228.15	<0.0001
FatR*FatL	9	241	28.22	<0.0001
SugarR*SugarL	6	241	546.45	<0.0001
Flour Protein* FatR*FatL	27	241	2.40	0.0002
FatR*FatL*SugarR*SugarL	54	241	3.46	<0.0001
Flour Protein*SugarR*SugarL	18	241	6.63	<0.0001
Flour Protein*FatR*FatL*SugarR*SugarL	162	241	1.02	0.4443
Cookie hardness with sucralose				
Flour Protein	3	241	42.65	<0.0001
FatR*FatL	9	241	34.96	<0.0001
SugarR*SugarL	6	241	78.07	<0.0001
Flour Protein* FatR*FatL	27	241	2.11	0.0017
FatR*FatL*SugarR*SugarL	54	241	1.88	0.0007
Flour Protein*SugarR*SugarL	18	241	3.33	<0.0001
Flour Protein*FatR*FatL*SugarR*SugarL	162	241	0.89	0.7964
Cookie spread				
Flour Protein	3	161	237.72	<0.0001
FatR*FatL	9	161	34.61	<0.0001
SugarR*SugarL	4	161	32.89	<0.0001
Flour Protein* FatR*FatL	27	161	1.86	0.0102
FatR*FatL*SugarR*SugarL	36	161	1.61	0.0244
Flour Protein*SugarR*SugarL	12	161	1.08	0.3818
Flour Protein*FatR*FatL*SugarR*SugarL	108	161	0.98	0.5447
Cookie hardness				
Flour Protein	3	161	43.58	<0.0001
FatR*FatL	9	161	29.11	<0.0001
SugarR*SugarL	4	161	5.61	0.0003
Flour Protein* FatR*FatL	27	161	1.97	0.0053
FatR*FatL*SugarR*SugarL	36	161	0.74	0.8525
Flour Protein*SugarR*SugarL	12	161	0.66	0.7866
Flour Protein*FatR*FatL*SugarR*SugarL	108	161	0.87	0.7885

PART 2

Source	Num DF	Den DF	Type III F	Pr>F
Cookie Spread				
Flour Protein	2	87	44.28	<0.0001
FatR	3	87	11.35	<0.0001
Flour Protein*FatR	6	87	0.27	0.9493
SugR	2	87	16.56	<0.0001
Flour Protein*SugR	4	87	0.54	0.7074
FatR*SugR	4	87	1.93	0.1121
Flour Protein*FatR*SugR	8	87	0.45	0.8901
Cookie Hardness				
Flour Protein	2	87	1.96	0.1468
FatR	3	87	22.55	<0.0001
Flour Protein*FatR	6	87	1.14	0.3487
SugR	2	87	2.06	0.1336
Flour Protein*SugR	4	87	0.43	0.7842
FatR*SugR	4	87	1.82	0.1321
Flour Protein*FatR*SugR	8	87	0.30	0.9633
Cookie protein				
Flour Protein	2	29	820.09	<0.0001
FatR	3	29	316.15	<0.0001
Flour Protein*FatR	6	29	0.36	0.8961
SugR	2	29	2.46	0.1033
Flour Protein*SugR	4	29	1.00	0.4227
FatR*SugR	4	29	0.21	0.9281
Flour Protein*FatR*SugR	8	29	0.72	0.6713
Cookie fat				
Flour Protein	2	29	0.44	0.6468
FatR	3	29	175.59	<0.0001
Flour Protein*FatR	6	29	0.58	0.7459
SugR	2	29	3.73	0.0361
Flour Protein*SugR	4	29	0.34	0.8464
FatR*SugR	4	29	0.17	0.9504
Flour Protein*FatR*SugR	8	29	0.40	0.9133

Source	Num DF	Den DF	Type III F	Pr>F
Cookie ash				
Flour Protein	2	29	5.92	0.0070
FatR	3	29	12.61	<0.0001
Flour Protein*FatR	6	29	0.61	0.7239
SugR	2	29	2.93	0.0695
Flour Protein*SugR	4	29	0.66	0.6241
FatR*SugR	4	29	0.82	0.5215
Flour Protein*FatR*SugR	8	29	1.01	0.4474
Cookie moisture				
Flour Protein	2	29	1.97	0.1576
FatR	3	29	75.14	<0.0001
Flour Protein*FatR	6	29	0.68	0.6663
SugR	2	29	1.44	0.2530
Flour Protein*SugR	4	29	0.52	0.7222
FatR*SugR	4	29	0.51	0.7277
Flour Protein*FatR*SugR	8	29	0.28	0.9690
Cookie L* value				
Flour Protein	2	141	5.89	0.0035
FatR	3	141	14.77	<0.0001
Flour Protein*FatR	6	141	3.37	0.0039
SugR	2	141	4.32	0.0151
Flour Protein*SugR	4	141	0.43	0.7891
FatR*SugR	4	141	1.39	0.2389
Flour Protein*FatR*SugR	8	141	1.15	0.3314
Cookie a* value				
Flour Protein	2	141	6.47	0.0020
FatR	3	141	44.25	<0.0001
Flour Protein*FatR	6	141	2.29	0.0383
SugR	2	141	5.33	0.0059
Flour Protein*SugR	4	141	0.88	0.4789
FatR*SugR	4	141	0.50	0.7381
Flour Protein*FatR*SugR	8	141	1.81	0.0805
Cookie b* value				
Flour Protein	2	141	8.55	0.0003
FatR	3	141	14.60	<0.0001
Flour Protein*FatR	6	141	0.88	0.5112
SugR	2	141	26.64	<0.0001
Flour Protein*SugR	4	141	1.63	0.1703
FatR*SugR	4	141	0.89	0.4689
Flour Protein*FatR*SugR	8	141	1.37	0.2167

Source	Num DF	Den DF	Type III F	Pr>F
Cookie hue angle				
Flour Protein	2	74	2.36	0.1011
FatR	3	74	22.26	<0.0001
Flour Protein*FatR	6	74	1.35	0.2467
SugR	2	74	2.61	0.0802
Flour Protein*SugR	4	74	0.46	0.7656
FatR*SugR	4	74	0.33	0.8540
Flour Protein*FatR*SugR	8	74	0.91	0.5129
Sensory baked color				
Flour Protein	2	547	6.81	0.0012
FatR	3	547	5.64	0.0008
Flour Protein*FatR	6	547	3.18	0.0045
SugR	2	547	1.38	0.2512
Flour Protein*SugR	4	547	1.75	0.1378
FatR*SugR	4	547	3.52	0.0075
Flour Protein*FatR*SugR	8	547	1.74	0.0857
Sensory cell size				
Flour Protein	2	547	16.61	<0.0001
FatR	3	547	5.27	0.0014
Flour Protein*FatR	6	547	0.57	0.7507
SugR	2	547	17.04	<0.0001
Flour Protein*SugR	4	547	0.12	0.9736
FatR*SugR	4	547	0.89	0.4668
Flour Protein*FatR*SugR	8	547	0.87	0.5390
Sensory surface roughness				
Flour Protein	2	547	36.43	<0.0001
FatR	3	547	84.13	<0.0001
Flour Protein*FatR	6	547	2.57	0.0184
SugR	2	547	32.61	<0.0001
Flour Protein*SugR	4	547	1.59	0.1751
FatR*SugR	4	547	0.24	0.9134
Flour Protein*FatR*SugR	8	547	0.70	0.6898
Sensory hardness				
Flour Protein	2	547	8.75	0.0002
FatR	3	547	77.98	<0.0001
Flour Protein*FatR	6	547	2.11	0.0510
SugR	2	547	1.61	0.2014
Flour Protein*SugR	4	547	1.27	0.2817
FatR*SugR	4	547	2.81	0.0251
Flour Protein*FatR*SugR	8	547	1.55	0.1378

Source	Num DF	Den DF	Type III F	Pr>F
Sensory fracturability				
Flour Protein	2	547	7.71	0.0005
FatR	3	547	55.61	<0.0001
Flour Protein*FatR	6	547	1.06	0.3839
SugR	2	547	6.77	0.0012
Flour Protein*SugR	4	547	1.96	0.0985
FatR*SugR	4	547	1.67	0.1561
Flour Protein*FatR*SugR	8	547	0.64	0.7448
Sensory moistness				
Flour Protein	2	547	2.06	0.1287
FatR	3	547	33.93	<0.0001
Flour Protein*FatR	6	547	3.95	0.0007
SugR	2	547	11.07	<0.0001
Flour Protein*SugR	4	547	0.98	0.4199
FatR*SugR	4	547	2.87	0.0225
Flour Protein*FatR*SugR	8	547	1.63	0.1134
Sensory molar packing				
Flour Protein	2	547	7.14	0.0009
FatR	3	547	16.73	<0.0001
Flour Protein*FatR	6	547	1.73	0.1124
SugR	2	547	6.44	0.0017
Flour Protein*SugR	4	547	0.70	0.5919
FatR*SugR	4	547	1.05	0.3807
Flour Protein*FatR*SugR	8	547	0.93	0.4872
Sensory almond flavor				
Flour Protein	2	547	6.43	0.0017
FatR	3	547	3.08	0.0271
Flour Protein*FatR	6	547	1.64	0.1342
SugR	2	547	1.89	0.1517
Flour Protein*SugR	4	547	1.04	0.3883
FatR*SugR	4	547	0.41	0.8041
Flour Protein*FatR*SugR	8	547	0.42	0.9084
Sensory sweetness				
Flour Protein	2	547	8.26	0.0003
FatR	3	547	1.23	0.2975
Flour Protein*FatR	6	547	1.05	0.3931
SugR	2	547	0.46	0.6296
Flour Protein*SugR	4	547	0.24	0.9162
FatR*SugR	4	547	2.31	0.0564
Flour Protein*FatR*SugR	8	547	0.96	0.4689

Source	Num DF	Den DF	Type III F	Pr>F
Sensory browned flavor				
Flour Protein	2	547	4.23	0.0150
FatR	3	547	3.41	0.0174
Flour Protein*FatR	6	547	1.41	0.2087
SugR	2	547	1.58	0.2072
Flour Protein*SugR	4	547	2.06	0.0846
FatR*SugR	4	547	1.97	0.0984
Flour Protein*FatR*SugR	8	547	1.55	0.1383
Sensory aftertaste				
Flour Protein	2	547	0.93	0.3937
FatR	3	547	0.88	0.4510
Flour Protein*FatR	6	547	0.45	0.8425
SugR	2	547	6.37	0.0018
Flour Protein*SugR	4	547	0.89	0.4684
FatR*SugR	4	547	0.60	0.6652
Flour Protein*FatR*SugR	8	547	0.31	0.9613

APPENDIX D

Table of Wire-Cut Cookie Spreads for All Treatments

Table D1– Least-squares mean estimates of cookie spread for wire-cut cookies formulated with 4 flour protein levels, 3 fat replacers at 3 fat levels, and 2 sugar replacers at 2 levels[a]

Flour protein level (%)	Fat reduction (%) Fat replacer	Full sugar	Isomalt (45)	Maltitol (45)	Isomalt (65)	Maltitol (65)
5.8						
	Full fat	7.6	6.2	10.2	9.1	9.4
	Reduced (35)					
	Betatrim	8.0	8.5	9.4	8.7	9.6
	Stardri	8.4	9.4	9.5	9.2	9.7
	Simplesse	8.3	8.9	9.2	9.4	9.6
	Intermediate (55)					
	Betatrim	7.8	7.4	8.0	8.4	8.6
	Stardri	7.3	9.7	9.4	9.0	9.7
	Simplesse	8.8	8.4	8.5	8.5	9.0
	Low (75)					
	Betatrim	6.5	6.8	6.8	6.8	6.7
	Stardri	7.0	9.1	6.8	9.3	9.1
	Simplesse	6.6	7.8	7.8	7.7	8.5
7.5						
	Full fat	6.9	6.4	6.5	6.8	8.9
	Reduced (35)					
	Betatrim	6.8	8.2	8.4	7.7	8.2
	Stardri	7.6	8.9	8.5	8.4	8.9
	Simplesse	7.1	7.7	8.2	7.9	8.6
	Intermediate (55)					
	Betatrim	6.6	7.1	7.1	7.5	7.2
	Stardri	7.5	8.4	8.5	8.0	8.6
	Simplesse	6.3	7.2	7.8	7.0	7.9
	Low (75)					
	Betatrim	7.0	6.5	5.9	6.2	6.7
	Stardri	7.3	8.3	8.3	8.1	8.8
	Simplesse	6.4	7.0	7.1	7.4	6.9

Table D1 – continued

Flour protein level (%)	Fat reduction (%) Fat replacer	Full sugar	Isomalt (45)	Maltitol (45)	Isomalt (65)	Maltitol (65)
8.8						
	Full fat	5.5	6.1	6.2	6.2	7.1
	Reduced (35)					
	Betatrim	6.4	7.0	7.0	7.3	7.1
	Stardri	7.2	7.5	8.0	7.1	7.9
	Simplesse	5.8	6.5	7.2	7.1	8.2
	Intermediate (55)					
	Betatrim	5.9	6.5	6.5	6.6	6.9
	Stardri	6.8	7.3	7.3	7.4	8.2
	Simplesse	6.2	6.6	6.5	7.0	6.9
	Low (75)					
	Betatrim	6.1	5.7	5.7	5.8	6.0
	Stardri	6.9	7.1	7.4	7.4	8.0
	Simplesse	5.6	6.1	6.0	6.1	6.6
10.4						
	Full fat	5.1	5.7	6.3	5.1	6.6
	Reduced (35)					
	Betatrim	5.9	5.3	6.7	6.3	6.3
	Stardri	6.3	6.4	6.9	6.1	7.2
	Simplesse	5.8	6.4	6.5	6.3	6.4
	Intermediate (55)					
	Betatrim	5.4	6.1	5.9	6.0	6.4
	Stardri	6.0	6.5	6.7	7.0	7.4
	Simplesse	5.4	5.8	6.1	4.4	6.2
	Low (75)					
	Betatrim	4.9	5.1	5.2	5.5	5.4
	Stardri	5.9	6.7	6.9	6.6	6.9
	Simplesse	5.0	5.6	7.3	5.8	5.5

Column header group: Sugar replacer and sugar reduction (%)

[a] Cookie spread calculated as width (cm) of 2 cookies / height (cm) of 2 cookies per treatment; average of 4 width measurements per cookie and average of 2 height measurements per cookie.

APPENDIX E

Sensory Evaluation Guides

Sensory Attributes[ab], Definitions, and References

Attribute	Definition/Anchors	References(Score[a])
Appearance		
Baked Color	Golden brown color without the appearance of being underbaked (very pale off-white) to dark brown. Very pale off-white -------------- Very dark brown	0 - underbaked cookie 75 - baked cookie 125 - dark brown cookie 150 - overbaked cookie
Cell Size	Size of the majority of the cells on the area of cut surface. A high value indicates large cells. Very small air cells---------------Very large air cells	0 - pound cake 75 - Zwieback cracker or glazed doughnut 150 - English muffin
Texture		
Surface Roughness	Degree to which top surface contains bumps or particles (geometrical) when lips are passed over surface. Smooth-----------Rough	0- jello 60 -vanilla wafer 125 -Pepperidge Farm Bordeaux cookie
Hardness	Force required to completely bite through sample when placed between the molars. Soft-----------Hard	0 - Archway soft sugar cookie 75- Shortbread cookie 150 - Gingersnap
Fracturability	Force with which cookie shatters. Crumbly ------------Brittle	10 - Pepperidge Farm Spritzer 70 - graham cracker 150 - Gingersnap
Moistness	Degree of perceived moistness or dryness. Dry-----------Moist	0 - crouton (very dry) 75- shortbread cookie 150 - moist cake or doughnut
Molar Packing	Amount of material left in and around the molar teeth at the end of chewing. None------------------Excessive packing	0 - jello 60 - graham cracker 150 - cheeseballs or puffs

Attribute	Definition/Anchors	References(Score[a])
Flavor		
Almond Flavor	Perception of a round, smooth, full sensation that may or may not be accompanied by the following flavor notes: sweet, almond, cherry, benzaldehyde. None --------------Very intense almond flavor	0- no almond cookie 75 - 0.22% almond cookie 125 -0.44% almond cookie
Sweetness	Degree of perceived sweet taste or intensity of sweetness. None-----------Very intense sweetness	10 - 80% sugar white cake 40 - 125% sugar white cake 120 - 140% sugar white cake 150 - 188% sugar white cake
Browned Flavor	Perception of a round, full-bodied medium aromatic associated with baked products; A blend of caramel, butter, burnt sugar and toasty flavor notes has been use to describe "browned flavor". None -----------Very intense browned flavor	0 - untoasted white bread 75 - lightly toasted white bread, Zwieback toast 150 - dark toasted white bread (intense brown flavor)
Aftertaste	Degree of lingering taste or flavor that persists 30 sec after swallowing None---------Very intense aftertaste	

[a] All attributes rated on a 0 (none) -150 (pronounced) scale
[b] Adapted from Armbrister and Setser (1994)

Cookie Panel
Evaluation Instructions

1. Type **panel2f** at the A: prompt.

2. Enter your **judge number** where it asks for "Name." Hit **RETURN/ENTER** key to go to your first sample.

3. Sample number will say " 1 " (this indicates your first sample). For the first line scale **enter the 2-digits** (sometimes 3) that corresponds to the sample number (on your cookie bag) by moving the cursor to the appropriate number on the line. Refer to the blue paper for these 2-digit codes. Hit **RETURN/ENTER key.**

4. Your first attribute should now be on the screen - "Baked Color" - Please evaluate by moving the cursor to the position on the line which represents the intensity of baked color. Please use references (pictures and definition page) for evaluating. Hit **RETURN/ENTER** key when finished.

5. Repeat step 4 for remaining 10 attributes. At this point, you may hit ESC key if you need to go back to an attribute and re-evaluate. Otherwise, if finished hit **RETURN/ENTER** key and you will proceed to the next sample number.

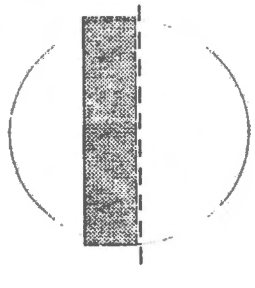
6. When you proceed to the next cookie sample, refer to blue sheet with the appropriate 2-digit (or 3-digit) code to move the cursor to on the line for the first question, then proceed to the attribute evaluation. (This is a repeat of step 3)

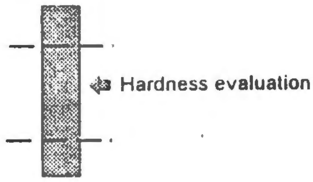
7. Once you have evaluated 5 cookies, you must hit **RETURN/ENTER** key - you must see the message **"Thank you for attending, have a nice day!"**. If you do not see this message, <u>ask for help</u>.

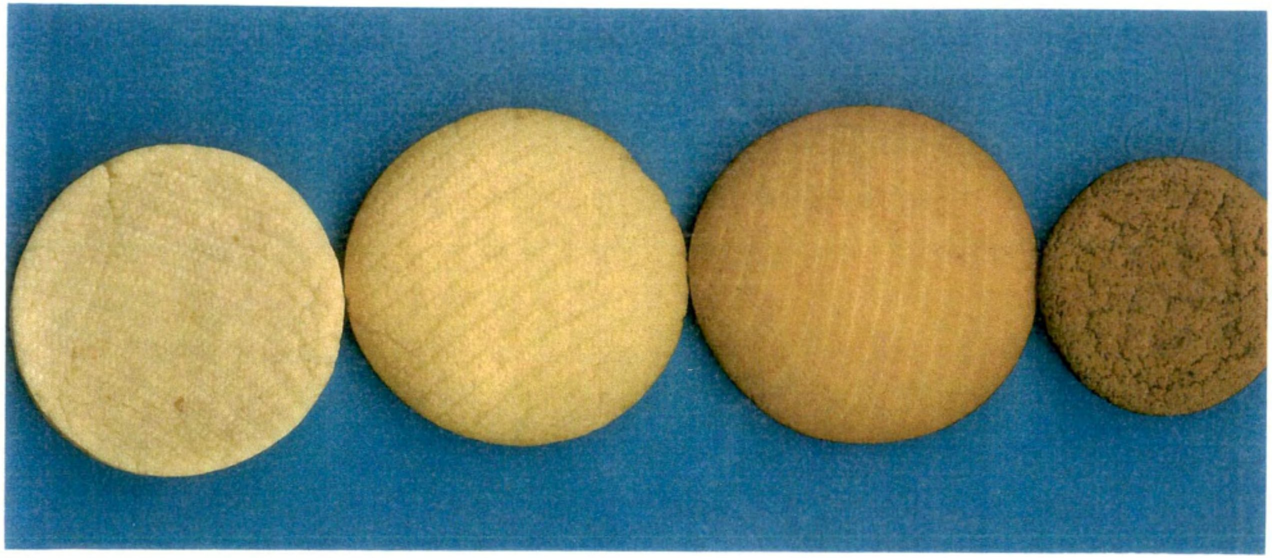
   To finish your session, press **Control-Break** bringing you to the A: prompt. Pop you disk out of the drive and turn it in after completion of the test.

********How to cut your cookie sample for air cell size and texture evaluation:**

- Use knife and cut in half - evaluate cross-section of cookie for air cell size
- Use one half of cookie for texture evaluation - cut approximately 1 cm by 2cm strip from one half avoiding the edges. Use this piece for hardness evaluation.
- Assess remaining texture attributes with remaining part of the cookie half.
- Use second half for flavor evaluation.

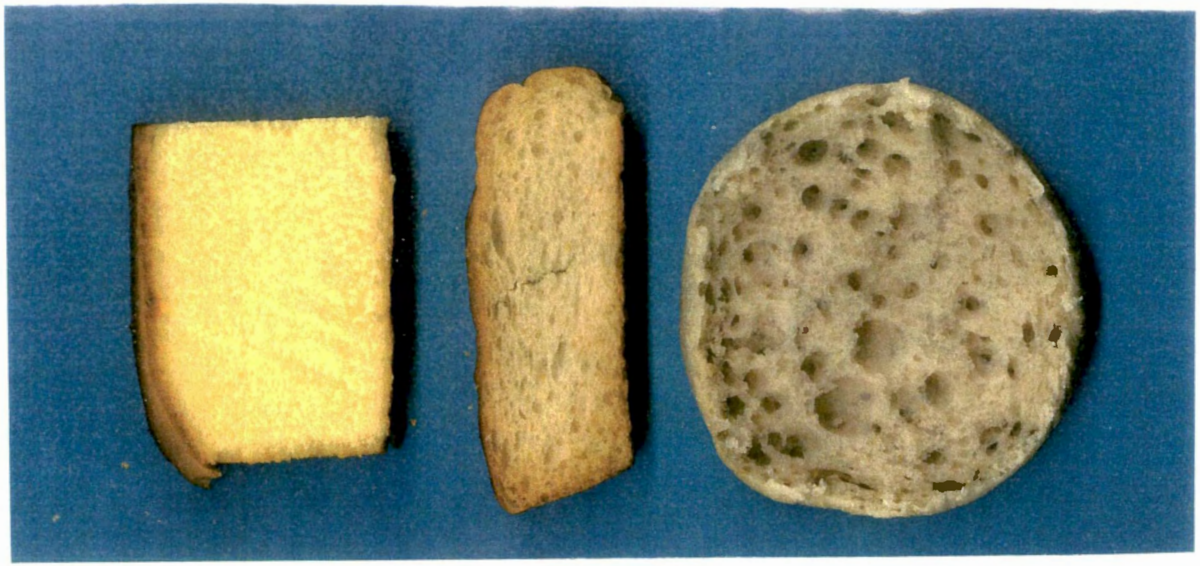






0------------------------------------50--------------------------------------125-------------------------------150
Very pale | Very dark brown

Attribute of baked color



0	75	150
Pound Cake	Zwieback Toast	English Muffin

Very small air cells--Very large air cells

Attribute of cell size

APPENDIX F

Table of Average Cookie Weights and Estimated Caloric Values per Serving

Table F1– Average weights and estimated caloric content per 1 cookie serving of wire-cut cookies varying in flour protein level, fat replacer, and sugar replacer

Wire-cut cookie formula			Serving size	Kcal
Flour protein level (%)	Fat replacer	Sugar replacer	1 Cookie (g) [a]	
5.5	Full fat	Full sugar	20.7	95.6
	Betatrim 35%	Full sugar	21.4	82.3
		Isomalt 65%	21.4	78.1
		Maltitol 65%	21.8	79.4
	Stardri 55%	Full sugar	21.6	78.2
		Isomalt 65%	20.9	70.6
		Maltitol 65%	21.2	71.6
	Simplesse 55%	Full-sugar	20.5	73.8
		Isomalt 65%	21.4	72.5
		Maltitol 65%	20.8	70.3
7.5	Full fat	Full sugar	21.6	99.7
	Betatrim 35%	Full sugar	21.2	82.3
		Isomalt 65%	22.1	80.0
		Maltitol 65%	21.2	78.2
	Stardri 55%	Full sugar	21.6	77.4
		Isomalt 65%	21.5	73.0
		Maltitol 65%	21.9	74.0
	Simplesse 55%	Full sugar	22.0	79.3
		Isomalt 65%	21.7	73.1
		Maltitol 65%	21.1	71.2
8.8	Full fat	Full sugar	21.4	98.7
	Betatrim 35%	Full sugar	21.9	83.9
		Isomalt 65%	22.4	81.3
		Maltitol 65%	21.7	79.8
	Stardri 55%	Full sugar	21.9	78.4
		Isomalt 65%	22.0	74.3
		Maltitol 65%	21.3	72.0
	Simplesse 55%	Full-sugar	21.2	76.0
		Isomalt 65%	22.0	73.7
		Maltitol 65%	21.9	73.8

[a] Mean weight of 8 cookies per treatment.
[b] Caloric content for fat estimated with projected caloric amounts of fat replacers (Betatrim = 1 kcal/g, Stardri = 4 kcal/g, and Simplesse = 4 kcal/g).
[c] Caloric content for carbohydrate estimated with projected energy values for sugar replacers (Isomalt = 2.0 kcal/g, Maltitol = 2.1 kcal/g).

VITA

The author, Kimberly A. Johnson, was born in Cincinnati, Ohio, the daughter of Mr. and Mrs. Nelson Kaiser. She has one brother, Paul Kaiser. She was educated in both parochial and public school systems in Cincinnati, Ohio, but graduated from Trinity High School in Euless, Texas. She earned her B.S. in Home Economics with a major in Dietetics at Texas Tech University, Lubbock, Texas. After becoming a Registered Dietitian in 1993, she completed her M.S. in Nutrition from Texas Woman's University, Denton, Texas in 1994. The author was employed in long-term care consulting, management, and clinical nutrition fields both during and after her Master's program. She worked for a leading food-service/dietetic contract company in Abilene, Texas for 18 months prior to entering the doctoral program in Food Science and Technology at The University of Tennessee, Knoxville. As a doctoral student, Kimberly has worked as graduate research and teaching assistant and has served as a part-time dietitian with East Tennessee Children's Hospital, Knoxville. She is a member of the American Dietetic Association, Institute of Food Technologists, American Association of Cereal Chemists, and Gamma Sigma Delta honor society. While attending The University of Tennessee, she married Joseph G. Johnson in February 1999.