REDUCED-IN-CALORIE COOKIES: IMPACT OF MODIFICATION ON STORAGE AND COLOR

by

ALISON MARIE KANE

Under the Direction of Dr. Ruthann Swanson

ABSTRACT

Experiment 1: Over a 7-day storage period, flavor and texture attributes of 3 formulations of 2 cookie types were profiled by a trained sensory panel, and texture was assessed using physical and physicochemical techniques. Data were analyzed with PROC MIXED and PDIFF ($p<0.05$), and PROC CORR ($p<0.01$). Sensory characteristics were minimally affected over time. Probing indicated more textural changes in oatmeal than chocolate chip formulations. Sensory hardness and fracturability were significantly correlated with all probe parameters for the oatmeal formulations.

Experiment 2: Cookie color was evaluated using two sensory techniques. CIELAB and hue angle were determined using two instrumental methods. ANOVA and PDIFF ($p<0.05$), PROC T-TEST ($p<0.05$) and PROC CORR ($p<0.01$) were used to analyze the data. All evaluation methods were successful. Sensory methods were similarly effective in identifying formula differences. A strong linear relationship existed between instrumental methods. Instrumental and sensory correlations validated the potential of both instrumental methods.

INDEX WORDS: Cookies, Reduced-in-calorie, Acesulfame-K, Prune puree, Storage, Texture, Flavor, Sensory evaluation, Instrumental evaluation, Probing, Color, Spectrophotometer, Digital camera

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CHAPTER I

INTRODUCTION

Obesity in the United States

Obesity and obesity-related health risks are growing concerns. Between 1991 and 1999, adult obesity rose almost 60% in the Unites States (Centers for Disease Control 2000). The most recent National Health and Nutrition Examination Survey (NHANES 1999) data published by the Centers for Disease Control indicates that the prevalence of overweight and obesity among adults is 61%. In that report, overweight was defined as having a body mass index [BMI, calculated as weight (kg)/height (m^2)] greater than 25 and obesity was defined as having a BMI greater than 30 (National Center for Health Statistics 2000). This definition of obesity loosely translates to 30 pounds overweight. The obesity epidemic has affected almost all 50 states and all demographic groups in the country (Centers for Disease Control 2000).

Overweight and obesity are associated with increased risk of diabetes, heart disease, stroke, hypertension, gallbladder disease, osteoarthritis, sleep apnea and certain forms of cancer. Obese individuals are projected to have a 50 to 100% increased mortality risk, mainly due to cardiovascular problems, as compared with normal weight individuals. Direct health care costs—including medication, hospitalization and physician visits—associated with obesity in 1995 are estimated at $51.6 billion, over 5% of the total United States health expenditure (NIDDK 2000).

The increase in obesity and overweight is attributable to several factors, including less opportunity for physical activity, greater availability of foods, a booming fast food industry, and the increased marketing of a variety of snack foods (Centers for Disease Control 1999). One of the objectives set by Healthy People 2010 is a reduction of obesity to less than 15% of the adult population (US Department of Health and Human Services 2000). While there is no simple way for Americans to reach this goal, improved nutrition and physical activity have been highlighted by the Centers for Disease Control (2000) as a means to control the epidemic.

Reversing the Trend

The Dietary Guidelines for Americans, updated in May 2000, highlight the need for low fat intake and moderate sugar intake (USDA 2000). The Guidelines indicate that although consuming excess sugar does not cause hyperactivity and diabetes, it does contribute to dental caries. It is estimated that Americans consume approximately 64 pounds of caloric sweeteners, including sucrose, each year (Sugar Association 2000a). The Guidelines also point out that to maintain a healthy weight, calories spared by cutting fat should be replaced with fruits, vegetables and grains instead of high-sugar foods that may be less nutritious and contribute unnecessary calories in the diet (USDA 2000).

Further, the Guidelines recommend that fat intake be limited to no more than 30% of total calories from fat (USDA 2000). Currently, Americans get an average of 34% of their calories from fat (Calorie Control Council 2000a). While some dietary fat is vital for energy, essential fatty acids, and fat-soluble vitamin absorption (USDA 2000), excess dietary fat is linked to increased risk for several health conditions, including obesity and certain cancers. Additionally, saturated fat intake is associated with elevated cholesterol levels and increased risk for heart disease (Calorie Control Council 2000b). Even as percentage fat calorie consumption is decreasing—down from 40% of calories from fat a decade ago (Calorie Control Council 2000c)—obesity is on the rise in the American population.

Functions of Sugar and Fat

Despite the growing interest in reducing obesity and eating for good health, it is difficult to limit fat and sugar intake. Both play crucial roles in the structure, appearance and flavor of many foods. Reducing or replacing sugar in a product is challenging because in addition to sweetening, sugar has several other functions. Sugar acts as a preservative in jellies and jams and delays the coagulation of egg proteins (Bowers 1992; Sugar Association 2000b). In baked goods, sugar acts as a tenderizer, provides nourishment for yeast, and is crucial to the incorporation of air into fat in the creaming process. Caramelization of sugar contributes to the flavor and color of baked goods and confections. Hydrolysis of sucrose produces the reducing sugars glucose and fructose, which participate in Maillard browning, a series of non-enzymatic browning reactions between amino groups and reducing sugars that also contributes to the color and flavor of baked products and other foods (Bowers 1992).

Aside from their use as flavoring agents and as carriers of other flavors, fats also have a variety of functions in food systems. Fats act as a heat transfer medium for fried foods, and are necessary to create emulsions. Fats provide tenderness and determine the grain of baked goods and are the foundation for many sauces, icings and confections (Bowers 1992).

Together, fat and sugar provide many desirable sensory attributes, like texture, flavor, aroma and mouthfeel, that appeal to the palate. The preference for sweet taste in foods has been demonstrated to be present at birth, and it is thought that fondness for fat develops by early childhood. Children learn quickly to identify the distinguishing tastes and textures of energy-dense foods and show a preference for these usually sweet and/or fatty items (Drewnowski 1997).

In cookies, sugar provides sweetness and helps develop the characteristic crisp, brittle texture (Davis 1995). Sugar also contributes to tenderness by inhibiting starch gelatinization and gluten formation. Fat also acts as a tenderizer in cookies by limiting gluten formation (Penfield and Campbell 1990). In addition to contributing flavor, fat carries fat-soluble flavors and regulates flavor release (Drewnowski 1992).

Importance of Appearance

Fat and sugar content impact appearance, including color and apparent texture. Product appearance, in turn, impacts consumer behavior, since consumers are unlikely to purchase or consume products that are visually unappealing (Setser 1984). Appearance of a food product determines whether a product will be eaten the first time and is often used as an indication of flavor (Lawless 1985).

Further, product color can influence overall appeal and perception of food flavors (Marsili 1996). Several studies have shown that color influences perception of sweetness and pleasantness as well as flavor identification and perception (Clydesdale 1993).

Consumer Trends and the Marketplace

Reduced-fat and reduced-sugar products can help consumers meet the recommendations in the Dietary Guidelines. Since 1997, over 3,000 low or reduced-fat products have entered the market (Calorie Control Council 2000b). Americans are interested in cutting fat and calories for better health. In the early 1990s, consumers spent $33 billion on weight-loss products and services, including low-calorie foods and artificially sweetened beverages. Eighty-seven percent of consumers surveyed in 2000 by the Calorie Control Council regularly chose lighter versions of their favorite foods. Of consumers who chose low-fat products, 65% reported that they ate the same amount or less of the low-fat product as compared with the full-fat version (Calorie Control Council 2000c).

Using reduced-fat products can significantly impact fat and energy intake. Analysis of data collected in a nationwide survey of eating behavior indicates consumers who replace at least some full-fat products with fat-modified products have, on the whole, significantly lower total fat, saturated fat, cholesterol and energy intakes than those who use only unmodified products. Study results also indicated that consumers who used some reduced-fat and some full-fat products had better overall micronutrient profiles (Petersen and others 1999).

Despite the benefits of fat-reduced products, reducing overall calorie intake may better effect weight loss. Harvey-Berino (1998) found that moderately obese subjects that reduced both fat and carbohydrate energy (daily caloric intake between 4,186—5,023kJ) lost significantly more weight than those on fat-restricted diets (daily fat intake between 22—26g) for a 24-week period. During the study period, both groups decreased energy intake; the energy-restricted group to a significantly greater extent. The energy restricted group decreased both fat and carbohydrate intake, whereas the fat-restricted group decreased fat intake and increased carbohydrate intake. The reduction of both fat and carbohydrate may be a more effective strategy for weight control, although adherence to a this diet may be problematic. Although both groups reported an increase in feeling deprived, only the energy-restricted subjects reported an increase in perceived inconvenience of the diet. Both studies (Petersen and others 1999; Harvey-Berino 1998) point to the need for reduced-fat and reduced-calorie products that consumers will find acceptable and desirable.

Current trends indicate consumers' desire for indulgent full-flavor items. Manufacturers are responding with the marketing of rich, full-fat and calorie snacks and baked goods. Cookies are big sellers in the snack food market, with fiscal year 2000 cookie sales at all retail outlets totaling 4.5 billion dollars (Sosland 2000). Chocolate chip is one of the most popular varieties, with 22.6% of the market share in FY 1997. Oatmeal cookies held nearly 5% of the market share (Wylie 1998). Sales of fat-free and reduced-fat products have declined in the recent past (Kohn 2000), a trend that has caused the leading manufacturer of reduced-fat and fat-free cookies and snacks to reformulate their line, increasing the fat content to improve taste. Advertising campaigns for these products increasingly emphasize taste over health benefits (Bloom 1998).

Despite this movement toward the indulgent, there is room in the marketplace for reduced-fat and calorie foods. Nearly 87% of adults consume reduced-fat, reduced-calorie or sugar-free products, citing health reasons as the main motivator (Calorie Control Council 2000c).

Rationale

Consumers are looking for full-flavored products, yet they want them to be healthy and convenient (Kohn 2000). Consumers expect the appearance and shelf life of reduced-calorie foods to be similar to that of unmodified foods. There is a lack of published literature concerning the effects of calorie reduction via reduction of sugar and/or fat on shelf life and appearance of foods.

Awareness of effects of fat and sugar reduction in popular consumer products may increase the number of acceptable products on the market. Increasing the acceptability and variety of reduced-fat and calorie foods may, in turn, help consumers make better food choices and improve their overall health.

Purpose and Hypothesis

In this study, the effect of partial replacement of fat and sugar on staling properties of oatmeal and chocolate chip cookies was examined. It was hypothesized that the modified cookies would have the same or longer shelf life as compared to the full-fat control cookies, based on sensory evaluation of flavor and sensory and instrumental evaluation of texture.

The effect of partial fat and sugar replacement on color of oatmeal and chocolate chip cookies was also examined. Two instrumental color measurement techniques were compared to two sensory evaluation methods. It was hypothesized that both instrumental color measurement techniques would be appropriate for this application. However, the digital camera/software method of color measurement was expected to correlate more closely with sensory panel's perception of color.

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CHAPTER II

REVIEW OF LITERATURE

Cookie doughs generally include a relatively low amount of flour for structure, high amounts of sugar or other sweeteners for tenderness and sweetness, shortening for texture, including tenderness, a leavening agent and various added flavors (Matz 1992). There are several classifications of cookies based on dough formulation and production method, including deposit, cutting machine, rotary molded, bar and wire-cut cookies. The rheological properties of these cookie types vary, depending on their formulation and the machinery used in production and shaping. Deposit cookies, the type used in this study, are generally 35-40% sugar, 65-75% shortening and 15-25% liquid eggs on a flour-weight-basis (Pyler 1988; Matz 1992).

Role of Sugar

Aside from providing sweetness, sugar plays several other roles in foods. Sucrose is fairly soluble and moderately hygroscopic, only absorbing water at higher relative humidity levels. Both properties are related to sugar's hydroxyl groups. One of the beneficial effects of these properties is sugar's tendency to decrease water activity (the amount of 'free' water) in foods and therefore increase shelf life by inhibiting microbial and mold activity. Sugar also affects viscosity, bulk and density of the food system. The hydration properties of sugar are important to air incorporation (creaming) and product stability (Davis 1995).

Sugar affects starch gelatinization and protein denaturation (Davis 1995). Starch gelatinization is the irreversible ‘collapse’ of the starch molecule when heated in the presence of water. Pasting follows gelatinization and results in the swelling of the starch granules and release of exudates (Atwell and others 1988), including amylose. Sugar inhibits the gelatinization of starch molecules in cookies because it competes for the little available water (Penfield and Campbell 1990) and lowers the effective water activity of the food system, increasing the energy required for gelatinization. Sugar also bonds to the starch molecules and ‘links’ them together. This decreases the flexibility of the starch chains and further increases the energy needed for gelatinization (Spies and Hoseney 1982). Further, sugar competes with flour proteins for the available water in the cookie formula, decreasing gluten formation and increasing tenderness (Penfield and Campbell 1990). In addition to promoting tenderness, these reactions allow for greater expansion during leavening before the product is set by heating (Bowers 1992).

Sugar is crucial to non-enzymatic browning processes that provide color and flavor. Caramelization occurs when sugar is raised to a temperature above its melting point (186°C for sucrose). After melting, sugar undergoes dehydration reactions that lead to the characteristic caramel flavor and brown color (Davis 1995). Because cookies are generally baked at moderate temperatures, the role of caramelization in cookie color and flavor is uncertain.

Maillard, or carbonyl-amine, browning is a series of reactions requiring an amine, water and reducing sugar. Sucrose is not a reducing sugar and does not participate in Maillard reactions. However, hydrolysis of sucrose produces glucose and fructose, both reducing sugars (Penfield and Campbell 1990). As the Maillard reactions progress and amino sugars develop, melanoidin pigments impart a brown color and volatile flavor compounds impart a caramel-like aroma to the food (Penfield and Campbell 1990; Davis 1995). Aside from the sugar itself, several other factors play a part in these reactions, including pH, temperature, rate of heating, water activity and presence of other ingredients (Godshall 1988).

Replacement of Sugar with Acesulfame-K

Alternative sweeteners, desirable for their contribution to sweetness without added caloric value, must meet certain criteria—safety, taste, solubility, stability and cost (Giese 1993)—before they can be considered for use.

Acesulfame K (ace-K) is an alternative sweetener approved by the FDA for use in chewing gums, dry beverage and dessert mixes, baked goods and candies and as a tabletop sweetener. It is not metabolized by the body and therefore is non-caloric. Ace-K is stable over a wide range of pH and is heat-stable to 225°C, making it well suited to bakery applications. Furthermore, it is shelf stable for at least five years when held at room temperature. Ace-K is readily soluble at room temperature and can be incorporated at any stage of the mixing process (Peck 1994). It is approximately 200 times as sweet as sucrose and has an immediate sweet taste. It does not have a lingering aftertaste, although at high concentrations, slight bitterness or a metallic flavor is detected by some consumers (Peck 1994; Giese 1993). The detectability of these off-tastes depends on other constituents present in the food system (Giese 1993).

Like other available alternative sweeteners, ace-K does not duplicate all the functions of sugar. Because of sugar’s multifaceted role in foods, even partial replacement in high-sugar food like cookies may dramatically alter flavor, texture, appearance, including color, and other characteristics. Volume will be lost, as the bulking and air incorporation properties of sugar are not duplicated by ace-K. Redlinger and Setser (1987) compared the properties of various sweeteners in baked and unbaked shortbread-type doughs and noted that none of the alternative sweeteners tested, including ace-K, participated in browning reactions when baked. Thus, the reduction or replacement of sugar may lead to a final product that is lighter in color and lacking some of the flavor compounds associated with browning reactions.

Shelf-stability of baked products may be affected by replacement of sugar with ace-K. Cookies prepared with three different bulking agents (polydextrose, powdered cellulose, and soy fiber) and sweetened with either sucrose or ace-K and were compared after a 1 week storage period. It was found that all cookie formulations required more force to break after the storage period, but all formulations containing ace-K, regardless of bulking agent, required less force to break than sucrose formulations both fresh and after 1 week of storage. A consumer panel described the cookies sweetened with ace-K as softer and cake-like, whereas the cookies made with sucrose were described as crisp (Bullock and others 1992).

In the U.S., an acesulfame-K and dextrose (glucose) blend is marketed as Sweet One by Stadt Corporation (Brooklyn, NY). According to package information, half the sugar in the formula can be replaced with an equivalent amount of Sweet One in baked goods. The manufacturer recommends that 50% of the original sugar remain in the formula to provide texture and color.

Dextrose, a reducing sugar, is produced by the hydrolysis of starch and is frequently found in commercial baked products (Penfield and Campbell 1990). Dextrose participates readily in Maillard reactions and undergoes caramelization at a lower temperature than sucrose. It is hygroscopic and competes with starch and protein for formula water, effectively decreasing starch gelatinization and gluten formation. Dextrose also acts as a humectant, and has a high osmotic pressure that discourages bacterial growth (Penfield and Campbell 1990).

Role of Fat

Fat provides 9 kcal/g of energy and has several vital roles in food systems (Stockwell 1995). In cookies in particular, fat contributes to aeration, lubrication and overall eating quality. Aeration occurs in creamed cookies during the first stage of mixing, when the fat and sugar are combined. Air cells are created by the abrasive action of the sugar granules on the fat. These cells are expanded by the leavening gases and water vapor during baking, producing a finer grain, tenderness and increased volume in the resulting product (Hegenbart 1995). Also, the sugar particles are segregated from one another by the fat, which further contributes to the tenderness of the product by preventing the melted sugar particles from recrystallizing together (Kuntz 1996).

Tenderness is also enhanced because fat lubricates the ingredients during mixing and coats the flour particles, effectively decreasing the formation of gluten by preventing the flour proteins from reacting with water in the formula (Hegenbart 1993). Fat increases mixability of the dough and prevents handling and release problems during production (Kuntz 1996).

Fat has important sensory qualities in food systems. Fat can impart flavor, as well as carry fat-soluble flavors and regulate flavor release. As fat-containing foods are eaten, volatile fat-soluble flavors are first perceived through the nose or mouth (Drewnowski

1992). As these foods are masticated and warmed in the mouth, there is a gradual release of fat-soluble flavors (Lucca and Teppers 1994) and the perception of the textural qualities imparted by the fat (Drewnowski 1992). In the absence of fat, fat-soluble flavors are released all at once, resulting in reduced flavor sensation (Setser and Racette 1992) or a perception of intense flavor that quickly disappears (Plug and Haring 1993). Reducing or replacing the fat in a product can change the flavor profile and increase the perception of off-flavors. It may be necessary to mask these changes by altering other components of the formula (Setser and Racette 1992).

Fat replacers must have acceptable qualities in three important areas: moisture control, tenderness, and flavor (Stockwell 1995). Freshness and moisture in baked goods are a consequence of the water-binding abilities of fats (Drewnowski 1992). A fat-replacer's moisture control ability is particularly important to the shelf life of the product (Hegenbart 1995). In the absence of fat, baked products may lose moisture to the atmosphere and become dry, or absorb moisture from the atmosphere and become soggy. Much of the literature hints that water activity in baked goods increases over time. If water activity does increase, this can lead to faster drying and staling, as well as potential microbial growth. Fats in baked goods slow moisture migration and therefore retard staling (Hegenbart 1993). Leaving even a small amount of fat in a product can improve the shelf life and contribute greatly to mouthfeel and flavor (Hegenbart 1995).

Replacement of Fat with Prune Puree

In baked goods, fruit purees contribute to flavor and moisture and can extend shelf life (Stockwell 1995). The flavor of prune puree is not distinctive and the puree carries other flavors well (Busetti 1995). Prune puree contains 7.5% soluble and insoluble pectins, which enhance air incorporation during creaming. Similar to the actions of fat, pectins also trap flavor components and release them slowly during mastication. Prune puree also contains 15% sorbitol, which acts as a humectant (California Prune Board 1999a) and sweetener (Busetti 1995). This may extend the shelf life of baked goods by holding moisture in the product. The malic acid in prune puree (2%) acts as the acid needed for some chemical leaveners and inhibits microbial spoilage. It also contributes to flavor throughout the mastication process, as it is released slower than other organic acids (California Prune Board 1999a). Although prune puree contains a high proportion of moisture, about 30% (California Prune Board 1999b), the sugars it contains help control water activity in the final product (Cantor 1996).

These properties make prune puree an appropriate fat replacer in many baked goods, especially dense, dark colored products. Using prune puree also eliminates or reduces the need to add emulsifiers, caramel colors and preservatives to some baked goods (Cantor 1996). These properties suggest that the use of prune puree as a fat replacer will increase the shelf life and result in a product that is darker than the original full-fat formulation. To formulate reduced-fat products with prune puree, it is recommended that half the added fat be removed, and half of that amount, by weight or volume, be replaced with puree (California Prune Board 1999a, 1999b; Busetti 1995).

In a study comparing chocolate chip cookies made with several fat replacers, prune puree was used to replace 100% of the fat (Charlton and Sawyer-Morse 1996). A consumer panel scored the cookies on a 9-point hedonic scale that ranged from like extremely to dislike extremely. Although differences between the modified cookies and the control in flavor, texture and overall acceptability scores were not significant, appearance, color and tenderness scores of the fat-free cookies were significantly lower than the full-fat control. Perhaps fat reduction rather than complete replacement would have improved these scores.

Swanson and Munsayac (1999) found that fat reduction through the use of prune puree in oatmeal and chocolate chip cookies resulted in consumer panel scores that equaled or exceeded the full-fat versions. The reduced-fat oatmeal cookies were liked better than the control and were perceived to be less stale than the control. The panel found no difference in acceptability and in staleness or off-flavors between the reduced-fat chocolate chip cookie and control. The cookies were evaluated approximately 38 hours after baking. Perry (2001) used a consumer panel to study the acceptability of the cookie formulations used in this project one day post-bake. It was found that the oatmeal reduced-in-fat and reduced-in-fat-and-sugar cookies were not significantly different from the full-fat control in either texture or flavor acceptability, and more closely resembled the 'ideal' cookie described by the panelists. Similarly, the modified chocolate chip formulations were closer to the 'ideal' than was the full-fat control. Texture acceptability of the modified chocolate chip cookies equaled the control, while the flavor was less acceptable than the control.

Nutrient values for the cookies are presented in **Table 2.1** and were previously reported by Perry (2001). The oatmeal reduced-in-fat and reduced-in-fat and sugar cookies had 17% and 22% fewer calories, respectively, as compared to the full-fat control. The chocolate chip reduced-in-fat and reduced-in-fat and sugar had 13% and 18% fewer calories, respectively, as compared to the full-fat control. In both cases, percentage of fat reduction exceeded that of calorie reduction.

Table 2.1. Nutrient analysis of oatmeal and chocolate chip cookies[1]

	Oatmeal[2]			Chocolate Chip[3]		
Nutrients per serving	Full-fat control	Reduced -in-fat[4]	Reduced-in-fat/sugar[5]	Full-fat control	Reduced -in-fat[4]	Reduced-in-fat/sugar[5]
Calories (kcal)	88.5	73.1	69.3	104.7	91.6	85.8
Protein (g)	1.2	1.2	1.2	1.2	1.2	1.2
Carbohydrates (g)	10.8	11.6	10.6	13.3	14.2	12.7
Fat (g)	4.6	2.5	2.5	5.5	3.7	3.7
Saturated fat (g)	1.9	1.0	1.0	3.7	2.4	2.4
Cholesterol (mg)	11.7	9.5	9.5	19.4	14.5	14.5
Dietary Fiber (g)	0.4	0.5	0.5	0.5	0.5	0.5
% calories from fat	46	31	32	46	35	38

[1] Nutrient analysis conducted using Food Processor, v. 7.21, ESHA Research, Salem, OR copyright 1998.
[2] Approximate serving size for oatmeal cookies was 19g.
[3] Approximate serving size for chocolate chip cookies was 23g.
[4] 50% of the added fat was replaced with prune puree (Sunsweet Growers, Inc., Yuba City, CA); prune puree substitutions were equal to 25% of the added fat in the original formula.
[5] In addition to fat reduction described above, 3g of Sweet One (Stadt Corp., Brooklyn, NY) replaced 50g of granulated sugar in oatmeal cookies and 4.5g of Sweet One replaced 75g granulated sugar in chocolate chip cookies.

Staling

A product's shelf life can be defined as the amount of time required before the product exhibits unacceptable physical, chemical, microbiological or sensory characteristics (Gacula 1975). The staling process is one component that determines shelf stability, and is described as the progressive non-microbial deterioration of quality of baked products resulting in decreased consumer acceptance. The consumer determines the degree of staleness, and therefore acceptability, by subjective means. The judgment is based on how the food smells and tastes, as well as how it feels to the touch and how it looks (Bechtel and others 1953).

Changes due to staling are more obvious in products with a high initial moisture content. Low-moisture cookies may undergo staling changes at a slower rate than other baked products (Burrington 1998). Soft, cake-like cookies, which may be up to 30%

moisture, may begin staling sooner than their low-moisture counterparts, which are typically crisp and tender (Smith 1970).

There is little in the literature regarding shelf-stability and staling processes of cookies and other low-moisture baked goods. In relatively high-moisture baked products like bread, staling is primarily due to starch retrogradation, moisture loss and loss of crumb cohesion (Cauvain 1999). Starch retrogradation occurs when gelatinized starch chains begin to bond together in an ordered crystalline structure (Penfield and Campbell 1990). However, starch in cookies is not gelatinized due to limited water availability, so this recrystallization process does not play a major role in cookie shelf stability.

Sugar recrystallization and associated changes in water distribution, however, may be important in the development of stale characteristics (Given 1993). Cookie shelf life may also be dependent on the stability of fats and flavorings used (Pyler 1988). The oxidation of fats can contribute to the development of off-flavors and changes in product aroma. Additionally, lipid oxidation reactions with some pigments and vitamins can affect the appearance and nutritive value of a product. Oxidation can occur when unsaturated fatty acids react with oxygen in the presence of air or in the presence of the combination of oxygen, light and a sensitizer, or due to enzyme activity (Love 1992). Changes in the flavor-binding and release properties of fat may play a role in the flavor changes associated with staling. It has been suggested that the shortening phase undergoes transitions that result in the perception of unpleasant crystals in the crumb (Given 1993).

Shelf Stability Analysis Techniques

Sensory Analysis

Because staling is defined by consumer sensory evaluation of a product, sensory analysis is vital to detecting and identifying changes in a product over time. Human sensory analysis of consumer products is crucial, as no instrument can duplicate human response (Watts and others 1989).

Sensory analysis is the analysis and measurement of sensory attributes using the human sensory system as an instrument. Sensory analysis methods can be divided into consumer-oriented and product-oriented evaluation. Consumer-oriented evaluation is usually aimed at determining consumer preferences or opinions about a product. A relatively large number of untrained product users (or potential users) are used in this type of study. In contrast, product-oriented evaluation is conducted to measure differences or intensities of product characteristics, such as flavor, odor, appearance and texture. Trained panels are generally used for product-oriented evaluation (Watts and others 1989).

Trained panels are generally small groups of people chosen for their sensitivity to the properties being studied, descriptive ability and abstract reasoning capacity. Panelists are trained to understand the terms used in testing and to use them in a consistent manner in order to provide objective and reproducible results (Meilgaard and others 1999). Trained panelists disregard personal preference when evaluating a product (Watts and others 1989). Descriptive tests are generally conducted with trained panels. The descriptive analysis process involves qualitative and quantitative assessment of product characteristics and the intensity of the characteristics. The panelists may develop their own terms and evaluation procedures and often use expanded rating scales (either category or line scales) or magnitude estimation scales (Meilgaard and others 1999).

In a study by Perry (2001), a trained panel was used to evaluate texture and flavor attributes of full-fat, reduced-in-fat and reduced-in-fat-and-sugar oatmeal and chocolate chip cookie formulations one day post-bake. Scores indicated relatively few significant flavor differences between the full-fat control and the modified cookies. For the oatmeal formulations, prune flavor intensity increased and butter flavor intensity decreased in both modified cookies. The reduced-in-fat-and-sugar cookie scored higher for brown sugar (molasses) intensity than either of the other formulas. The chocolate chip cookie formulas only differed in butter and brown sugar (caramelized) flavor intensities, with the brown sugar intensity increased and the butter flavor intensity decreased in the modified cookies. No differences in intensity were found for any of the basic tastes or vanilla, soda, or spices.

Greater differences were found for texture attributes. Both oatmeal and chocolate chip cookie types differed in manual and oral hardness, oral fracturability, cohesiveness and chewiness. The oatmeal formulas also differed in manual fracturability and the chocolate chip formulas differed in roughness. No differences were found for oiliness, oily mouthcoat or residual particles (Perry 2001).

Physicochemical and Physical Analysis

Several physical and instrumental methods of analysis are used to determine physical and textural characteristics of foods. Although sensory analysis is critical to fully describing the characteristics of a product, it is often costly and time consuming. Instrumental methods that accurately assess textural changes that accompany staling and that are validated by sensory methods are needed for bench-top testing and quality control of modified products (Meilgaard and others 1999). Methods used to evaluate cookie texture and quality include cookie spread, water activity, the three-point beam test and the puncture test.

Cookie Spread

Cookie spread, the ratio of cookie width to height (AACC 10-50D, 2000), is a physical indication of cookie flour quality (Doescher and others 1987) and is often used in industry as a quality control measure (Matz 1992). Cookie spread is determined by obtaining an average width and thickness of six randomly selected cookies. The width:thickness ratio is then calculated, correcting for barometric pressure on the day of baking.

Spread is affected by formulation, including flour quality, sugar (Matz 1992), processing and baking conditions (Pyler 1988) and humidity. Atmospheric pressure changes have also been shown to influence cookie spread (Morrow and others 1974).

The amount and granulation of sugar affect spread. Besides the obvious loss of bulk when the volume of sugar is decreased, lower sugar concentration results in increased gluten formation and decreased cookie spread because more water is available to interact with flour proteins (Doescher and others 1987; Matz 1992). Vetter and others (1984) concluded that spread is decreased with decreasing levels of dissolved sugar in the dough after finding that cookie formulas containing 60% sucrose spread more than those containing 50% or 40% sucrose and that decreasing granulation size also resulted in increased spread. Vetter and others (1984) also noted that cookies made by the all-in method spread slightly more than those made by the creaming method because in the creamed formula, the sugar particles are coated with fat and dissolve less readily. The type of sugar also impacts spread. Doescher and others (1987) demonstrated that cookies formulated with glucose and fructose set faster and thus, were significantly smaller than those formulated with sucrose.

The use of fat replacers can also decrease spread. Fat replacers often result in increased formula water, which increases gluten development during mixing. Formula water can also be affected by the inclusion of oatmeal and other coarse materials as a function of their moisture content; dough water must be adjusted accordingly. Decreased or uneven spread may also result from the inclusion of these ingredients due to their decreased surface area (Matz 1992).

Because spread is dependent on cookie formulation and manufacturing process, it is used here as a relative indication of differences between formulas. It is expected that the full-fat control formula will spread more than the reduced-in-fat and reduced-in-fat and sugar formulas because of the higher volume of fat and sugar. Reduction of sucrose is also expected to decrease spread due to the loss of bulk and increased gluten formation. Perry (2001) reported decreased spread for the modified cookie formulas used in this study. Full-fat control cookies were relatively thin with a large diameter, while fat reduction resulted in decreased diameter and increased thickness, and sugar and fat reduction further decreased spread and increased thickness.

Water Activity

Water activity is a measure of the unbound water in a system. It indicates the amount of water available to act as a solvent, participate in reactions and support microbial growth. Knowing the water activity allows prediction of a food's safety, stability, reactivity and physical properties. Water activity is evaluated instrumentally by measuring either the dew point or the relative humidity of a sample (Fontana 2000).

Most foods have water activity levels between 0.2 and 1.0. A high water activity (above 0.90) will support the growth of spoilage bacteria, and most molds and yeasts can survive at water activities above 0.6. Cookies are generally not susceptible to spoilage organisms, as the water activity for a traditional low-moisture crisp cookie is around 3.0 (Fontana 2000).

Water activity also impacts both non-enzymatic browning reactions and lipid oxidation reactions. At very low water activity levels—less than 0.2—lipid oxidation occurs at a rapid rate, whereas essentially no non-enzymatic browning occurs. Both reactions occur at a very rapid rate at a mid-range water activity of 0.6—0.7 and exhibit a rate decrease at water activity levels above 0.8. This indicates that the production of off-tastes and odors due to lipid oxidation is at a maximum at very low and middle to high water activities. A mid-range water activity is preferred for the keeping quality of lipid-containing foods (Fontana 2000). The potential for lipid oxidation is at its minimum at 0.3 to 0.4, indicating that oxidation reactions may not be a significant contributor to the changes associated with cookie staling in this study if water activity does not increase dramatically over the storage period.

Water activity is also important to the texture changes associated with staling of baked goods, due in large part to its role in the retrogradation rate of starches. When the water activity of low-moisture foods increases, the sensory perception of these foods may change from crisp and crunchy to soggy. Conversely, the sensory properties of high water activity foods change from tender, moist and chewy to hard, dry, stale and tough when water activity decreases (Fontana 2000).

Fat or sugar replacement may impact water activity. Prune puree is 30% moisture, so it has the potential to increase water activity. However, sorbitol in the puree acts as a humectant and binds water, and may effectively reduce water activity. Sucrose binds water, decreasing water activity. Acesulfame-K manufacturers claim that ace-K has no impact on moisture balance (Peck 1994). The dextrose in the sweetener blend may decrease water activity due to dextrose's humectant properties. However, the amount of dextrose incorporated is very small. Perry (2001) found that water activity of these cookie formulas, measured one day post-bake, increased slightly with modification, but not to a level that would support microbial growth.

Puncture test

Traditionally, instrumental tests to determine texture changes that occur with staling in cookies have been limited to the three-point beam test. This test is used for crisp cookies and crackers, and from the results it is possible to determine the force needed to break the sample, the distance of the crossarm from origin when the sample cracks and the slope for the application of force (Johnson 1992). This test, which involves supporting a sample on two beams and lowering a third beam down between the support beams until the sample breaks (Bourne 1982), may be inappropriate for softer, more pliable products like soft, chewy cookies, which tend to bend rather than break when subjected to this test.

In contrast, the puncture test measures the characteristics of the product from the outside surface into or through the product, including hardness of crust, softness of the interior and changes due to particles in the product (Johnson 1992). This test measures the force required to press a cylindrical probe into and/or through a food sample (Bourne 1975). To perform the puncture test, also referred to as probing, the sample is positioned on a plate that may or may not have a hole in it to accept the probe, depending on the depth of the puncture. The instrument lowers the probe into the sample at a set rate and depth and measures the force needed. A curve is generated depicting the point at which the sample yields to the probe and changes in resistance to the probe as it passes through the sample matrix. Measurements obtained by puncture testing can be interpreted to indicate the firmness (Bourne 1975), hardness (Gaines 1994) or toughness (Sanchez and others 1995) of a food. Probing has been used successfully with chewy products, such as bagels and fig bars (Johnson 1992), and may be more suitable for measuring texture changes in soft cookies then the three-point beam test.

Care must be taken that the probe is small enough as compared to the product diameter to maintain semi-infinite geometry and prevent effects from the sample sides, bottom, edges or corners. The recommended sample diameter to punch diameter ratio is 3:1. It is also important that an appropriate support plate be chosen. For thin samples like cookies, the plate must have a hole 1.5 to 3 times the diameter of the probe, centered directly under the probe. This allows the probe to pass completely through the sample without crushing it (Bourne 1999). Probing is a destructive test, yet in most cases, several measurements can be obtained per cookie, reducing within-cookie variation and the total amount of sample needed.

Gaines and others (1992) used probing and an untrained sensory panel to measure hardness of three types (micro- and macro-method AACC formulations and a wire-cut formulation) of sugar-snap cookies. Peak force resistance data was collected two days after baking and compared to the panelists ranking on a four-point hardness scale. The relative hardness as determined by probing was often reflected by the panel's mean hardness rating and degree of standard error. Changes in hardness over three days post bake were also investigated by probing. Only the micro-method cookies exhibited a significant decrease in probe resistance over time. The wire-cut cookies showed a trend toward decreased resistance. Both micro-method and wire-cut formulas had a relatively high shortening:water ratio, so less gluten formed and there was less interference with sugar recrystallization. This may have contributed to the decreased resistance to probing over time that these cookies exhibited.

Perry (2001) investigated the cookie formulas used in this study by probing and trained sensory panel. Cookies were evaluated 12-14 hours post-bake. Correlation analysis indicated that area under the curve, rather than force or slope, was the best indicator of cookie texture. Area correlated with oral hardness, chewiness and cohesiveness for both cookie types.

Color

Food is assessed for consumer acceptability by examining appearance, flavor, texture, safety and nutritive value. Appearance is of particular importance, since consumers are unlikely to purchase or consume products that are visually unappealing (Setser 1984). A food may be rejected because its color may warn the consumer of off-flavors or spoilage. These relationships between color and food safety, acceptability and preference are generally learned associations. Color has been shown to affect taste thresholds for sweet, sour and bitter and to affect the perception of sweetness.

Additionally, color has been shown to provide important cues for flavor identification in foods that lack distinguishing textural cues, such as sherbets and soft drinks (Clydesdale 1993). Color evaluation has a number of applications in the food industry including research, quality control, product tolerances (Francis 1983) and monitoring process steps (Mabon 1993).

Color Measurement and Evaluation

The CIE (Commission International de l'Eclariage) created one of the most widely used color measurement systems based on the premise that perception of color involves the interaction of an object, light and the eye. Researchers determined experimentally that subjects viewing a 2-degree area of colored light of any wavelength could match the color by combining different intensities of three other colored lamps, called primaries. The amounts of each of the primaries that were combined to match the test color are called the tristimulus values of the test color. In some cases, negative values were obtained when it was necessary to add one of the primaries to the test color in order to obtain a match with the remaining two primaries. To eliminate these negative values, the tristimulus values were mathematically transformed to a new set of primaries, called X, Y and Z. These primaries cannot be produced by any real light source, but rather are based on human color vision. These experiments formed the basis for the CIE 1931, or 2-degree, Standard Observer function (Billmeyer and Saltzman 1981).

The CIE standard observer functions are representative of the average normal color vision of the general population and justification for them is based on the anatomy of the eye, although they are somewhat arbitrary in their derivation. The human eye has two types of receptors: rods, which function at low illumination levels and do not participate in color vision, and cones, which function at high illumination levels and are important for color vision. Both types of receptors are distributed across the retina, however; only cones, which are important for color vision, are found in the fovea, a small area of the retina where an image falls when an object is viewed directly (Goldstein 1999).

The 2-degree observer was developed as described in the above experiment using only the fovea of the eye (Billmeyer and Saltzman 1981) in order to minimize variation between observers due to Maxwell's spot, an area of macular pigment of varying density found in the center of the retina. Experimental color matches were made based on the pigmented spot, and even though the intensity of pigment in Maxwell's spot varies between observers, color matching based on this area of the eye is generally stable and not significantly affected by adaptation conditions. Although observations made using the 2-degree observer function have the advantage of being made in the area of greatest color discrimination sensitivity, the macular pigment does produce variation between color matches made with the fovea versus those made with the area around the fovea (Wright 1987).

The CIE 1964, or 10-degree Standard Observer was developed using a similar experiment to the one described above. It was developed for industry applications that required color-matching capability across larger areas, and simulates an annular 10-degree field of view with the center 3-4 degrees excluded. This exclusion is designed to eliminate the effect of Maxwell's spot (Wright 1987). Because visual color assessment generally encompasses a large field of vision, it has been found that the 10-degree observer agrees better with human color assessment than the 2-degree observer under these conditions (Billmeyer and Saltzman 1981). An object's color can also appear different depending on the light source illuminating the object, therefore, the CIE has recommended several standard light sources and illuminants for use in color measurement (Billmeyer and Saltzman 1981).

Color space is the term commonly used to describe a method of systematically expressing the color of an object or light source. In 1976, the CIE introduced the L*a*b* color model (CIELAB), based on non-linear transformation of the tristimulus values described above. CIELAB is an opponent model that describes color in terms of lightness (L*) ranging from 0 to 100, redness or greenness (+/-a*) and yellow or blueness (+/-b*). Hue angle ($\tan^{-1}b^*/a^*$) describes color in degrees, starting on the a* axis with +a* (red) at 0° and proceeding counterclockwise around the color space with +b* (yellow) at 90°, -a* (green) at 180° and –b* (blue) at 270° (Billmeyer and Saltzman 1981) and is often used in food color measurement because it is easy to conceptualize and thought to be more closely related to human color perception.

Both tristimulus values and the CIELAB opponent color space are based on human color vision. The tristimulus, or trichromatic theory, was developed by Thomas Young in 1802 and later supported by work done by Herman Helmholz in 1952. Based on color matching experiments with three primaries, the researchers proposed that there were three physical processes responsible for color vision. Also in the early 1800's, Ewald Hering proposed a seemingly contradictory theory, called the opponent theory. Hering also proposed that there were three mechanisms behind color vision: a red-green process, a blue-yellow process, and a black-white process. His theory was based on observations of simultaneous contrast and afterimage effects. Hering also noted that in cases of human color deficiency, the inability to detect red was always paired with the inability to detect green. Likewise, inability to detect blue and yellow were similarly paired (Goldstein 1999).

Physical evidence was later found that supported both theories. The discovery of three types of cones in the human eye, the short-, medium- and long-wavelength cones, supported the tristimulus theory. The stimulation of the three cone types varies depending on wavelength. Opponent cells that respond to red and green or blue and yellow stimuli were discovered in the retina and visual cortex. These respond to stimulation by the cones through complex neural mechanisms, eventually resulting in the perception of color (Goldstein 1999).

Color Analysis Techniques

Sensory Analysis

Human color vision is fairly consistent (barring any deficiencies or abnormalities), and small panels comparable to those described in the shelf stability analysis techniques section can be used for sensory color evaluation (Setser 1984). This analysis can be a costly, complicated, and lengthy process. Human color evaluation can be affected by light source, surrounding colors and communication and descriptive abilities (Mabon 1993). When physical sample systems are used for sensory color evaluation, confusion can arise when attempting to describe, match or communicate a color that falls between the limited samples available (Francis 1983).

Hodgson and others (1993) evaluated the color of reduced-fat vanilla cookies with a trained panel, using a 15-cm unstructured line scale anchored by the terms ‘light’ and ‘dark’. A Hunter color difference meter was also used to obtain Hunter Lab values for the cookies, which contained either 20%, 40% or 60% polydextrose as a fat replacer. Both sensory and instrumental results reflected a significantly darker cookie with increasing fat replacement level.

Instrumental Analysis

It is fundamental that instrumental color measurement techniques are accurate, convenient, precise and quantitative (Marsili 1996), and that they are reflective of human sensory perception of color (Setser 1984). There are no universally acceptable methods for food color measurement, but filter colorimeters and color spectrophotometers are the two technologies commonly used (Mabon 1993).

Instrumental color measurement has been used to determine the effects of product modifications, including the effect of calorie reduction on the appearance of cookies. Swanson and others (1999) used a color spectrophotometer to evaluate the difference in color resulting from the use of a carbohydrate-based fat replacer in peanut butter cookies. Fat was replaced at either 75% or 100% levels with varying amounts of emulsifier. L, a and b values and hue angle were reported. Only the L value was affected by fat replacement; the modified cookies were significantly lighter than the control. In a study of fat reduction using polydextrose in vanilla cookies, Hodgson and others (1993) used a Hunter Color Difference Meter to measure Hunter L, a and b values at 20%, 40% and 60% fat replacement levels. Cookies had significantly lower L values (were darker) at the 40% and 60% replacement levels as compared to the 20% level. All modified cookies also exhibited significantly different ‘a’ values.

Color Spectrophotometer

The color spectrophotometer generates a spectral curve representing the reflectance or transmittance of light from the surface being measured as compared to that reflected by a reference standard. Several sensors in the instrument measure the spectral reflectance of a small area of the object at each wavelength or narrow range of wavelengths. The instrument uses the values from the reflectance measurements to calculate tristimulus values, which can then be converted to CIELAB or other color space values. The spectral power distributions of a variety of standard illuminants are stored in the instrument, allowing for measurement results to be calculated under a variety of illuminants. The color spectrophotometer used in this study uses d/8 spherical geometry. The light source is located in a spherical globe coated with reflective material. When light is emitted by the instrument, it scatters and bounces throughout the sphere, illuminating the sample with diffuse light. Samples are viewed at an 8-degree angle from the normal (Mabon 1993).

Digital Camera/Software system

A new method of color measurement for food products, introduced by Papadakis and others (2000), involves using a high-resolution digital camera to record images of a product under a standard CIE light source. The digital images are opened in Adobe Photoshop (Adobe Systems, Inc., San Jose, CA), a software program that is capable of displaying and reporting color values according to the CIELAB color model. This measurement method has the advantage of allowing color measurement across a user-defined area of the food surface, in contrast to the ‘point’ measurement obtained by a current color measurement tools like the color spectrophotometer. Additionally, the color image can be preserved for future reference. Papadakis and others (2000) have used this system successfully to measure the color of cereal bars and microwave pizza crusts.

Objectives

The primary purpose of this research was to investigate the effects of calorie reduction through sugar and/or fat reduction on staling and color of oatmeal and chocolate chip cookies. An additional purpose was to compare a new method of food color measurement to a method currently used. It was expected that the reduced-calorie cookies would have the same or longer shelf life, based on staling rate, than the full-fat control cookies. It was expected that the color of the reduced calorie formulas would differ from the control. It was also expected that both instrumental color measurement techniques would be appropriate and would indicate differences between individual cookies due to differences in formulation. However, the digital camera/software method of color measurement was expected to relate more closely with sensory color measurement results.

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CHAPTER III

METHODS

Shelf Stability—Experimental Design

Shelf-stability was assessed with both sensory and physicochemical/instrumental tests. A randomized incomplete block factorial design was utilized in the sensory portion of the study. Oatmeal or chocolate chip cookie type was blocked over the complete design. Trained sensory panelists (n=8) evaluated the three treatments—full-fat control (FFC), reduced-in-fat (RF) and reduced-in-fat and sugar (RFS)—on days 1 and 3 or days 5 and 7 of storage during a single session. The sensory portion of the study was replicated 3 times. A randomized complete block factorial design was utilized for the physicochemical and instrumental tests. This portion of the study was replicated six times. Factorial designs for each test are shown in **Table 3.1**. Cookies were randomly assigned for sensory and instrumental evaluation.

Color—Experimental Design

A randomized complete block factorial design was utilized in the color study. Trained sensory panelists (n=8-10) evaluated the three treatments—FFC, RF and RFS—of one cookie type during a single session. Cookies were evaluated three days after baking. The treatment combination used for the trained sensory panel was also used for instrumental color analysis. Two replications were obtained, 3 days post-bake. Factorial designs for each test are shown in **Table 3.1**.

Table 3.1. Factorial design of sensory and instrumental tests

Sensory Tests	
Trained Panel—Shelf Stability	2x3x4x3x8[1]
Trained Panel—Color	2x3x2x1x8-10[2]
Physical/Physicochemical/Instrumental Tests	
Cookie Spread	2x3x6x2[3]
Water Activity	2x3x6x4x4[4]
Probing	2x3x6x4x4-5x9[5]
Color Spectrophotometer	2x3x2x3x2x1[6]
Software Method	2x3x2x3x1[7]

[1] cookie type x treatment x storage days x replications x panelists

[2] cookie type x treatment x replications x samples x panelists

[3] cookie type x treatment x replications x samples; AACC Method 10-50D (2000)

[4] cookie type x treatment x replications x storage days x samples; measured using AquaLab (Decagon Devices, Pulman, WA). Aliquots were taken from composite samples as described by Curley and Hoseney (1984).

[5] cookie type x treatment x replications x storage days x samples x assessments; measured using a 50 kg capacity TA.XT2 Texture Analyzer equipped with Texture Expert, version 1.20, Stable Micro Systems, Haslemere, Surrey, England, with a 0.3 cm probe at a crossarm speed of 5 mm/sec as described by Bourne (1975, 1982) and Gaines and others (1992).

[6] cookie type x treatment x replications x samples x assessments x standard illuminant; measured using a Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ), specular component excluded, with instrument set to 10-degree observer function, using cool white fluorescent (F6) illuminant

[7] cookie type x treatment x replications x samples x illuminant setting; measured using Adobe Photoshop 6.0 software (Adobe Systems Inc., San Jose, CA), Olympus 3000ZOOM camera (Olympus America Inc., Melville, NY), and a Macbeth SpectraLight II light booth (Macbeth, Kollmorgen Instrument Corp., New Windsor, NY) under cool white fluorescent illuminant.

Sample Preparation

Cookie formulations, developed by Swanson and Munsayac (1999) and Perry (2001), are presented in **Table 3.2** and **Table 3.3**. For both cookie types, the RF and RFS versions incorporate prune puree as a fat replacer at the levels recommended by the California Prune Board (1999). Half of the initial amount of added fat was removed from the formulation and 25% of the initial amount of fat was replaced with prune puree. Sugar replacement with an acesulfame-K/dextrose blend (Sweet One®) was also made according to manufacturer's recommendations (Sweet One® 1998). For both types of RFS cookies, half of the granulated sugar in the control formulation was removed and

Table 3.2—Formula and Procedure[1] for Oatmeal Cookies

Ingredients	**Control (g)**	**Reduced Fat (g)**	**Reduced Fat & Sugar (g)**	**Product Information**
All-purpose flour	222.6	222.6	222.6	Con Agra, Inc., Omaha, NE
Old fashioned oats	160.0	160.0	160.0	The Quaker Oats Co., Chicago, IL
Granulated sugar	100.0	100.0	50.0	Monarch Regency, Greenville, SC
Sweet One®	n/a	n/a	3.0	Stadt Corp. Brooklyn, NY
Light brown sugar	165.0	165.0	165.0	Dixie Crystals, Diamond Crystal Brands, Inc, Savannah, GA
Baking soda	3.0	3.0	3.0	PYA/Monarch, Inc., Greenville, SC
Iodized salt	2.8	2.8	2.8	Flavor House, United Salt Corp., Houston, TX
Ground cinnamon	1.1	1.1	1.1	Kroger Corp., Cincinnati, OH
Ground cloves	0.3	0.3	0.3	Kroger Corp., Cincinnati, OH
Ground nutmeg	0.6	0.6	0.6	Kroger Corp., Cincinnati, OH
Imitation vanilla flavor	2.0	2.0	2.0	Greinoman's/Unified Industries, Inc., Cumming, GA
Large, Grade A egg	85.0	85.0	85.0	Kroger Corp., Cincinnati, OH
Vegetable shortening	125.0	62.5	62.5	Crisco, Proctor & Gamble, Cincinnati, OH
Salted butter	104.0	52.0	52.0	Land O Lakes, Inc., Arden Hills, MN
Dried plum puree	n/a	61.0	61.0	Sunsweet Growers, Inc., Yuba City, CA

[1] Procedure: Ingredients were mixed with a Kitchen Aid mixer (model K5SS, St. Joseph, MI) equipped with a paddle beater and baked in a rotary oven (National Manufacturing Co., Inc. Lincoln, NE). Flour, soda, salt, oats, sugar, brown sugar, cinnamon, cloves, nutmeg (and Sweet One® when appropriate) were blended in a mixing bowl at speed 1 for 2 minutes. Shortening, butter, eggs, and vanilla (and dried plum puree when appropriate) were added and mixed at speed 2 for 1 minute. 15±1g of dough was scooped with a #70 scoop. Dough was placed in 6 rows down and 3 across on a baking sheet (41.9 cm x 30.5 cm). Each pan was lined with parchment paper and lightly sprayed with Pam non-stick cooking spray (International Home Foods, Inc., Parsippany, NJ). Dough was rolled to 0.6 cm thickness (AACC 10-50D, 2000). Reduced-in-fat and reduced-in-fat-and-sugar cookies were baked at 176ºC (350ºF) for 9 minutes; full-fat control cookies were baked for 11 minutes.

Table 3.3—Formula and Procedure[1] for Chocolate Chip Cookies

Ingredients	Control (g)	Reduced Fat (g)	Reduced Fat & Sugar (g)	Product Information
All-purpose flour	308.6	308.6	308.6	Con Agra, Inc., Omaha, NE
Granulated sugar	150.0	150.0	75.0	Monarch Regency, Greenville, SC
Sweet One®	n/a	n/a	4.5	Stadt Corp. Brooklyn, NY
Light brown sugar	109.0	109.0	109.0	Dixie Crystals, Diamond Crystal Brands, Inc, Savannah, GA
Baking soda	3.0	3.0	3.0	PYA/Monarch, Inc., Greenville, SC
Iodized Salt	5.5	5.5	5.5	Flavor House, United Salt Corp., Houston, TX
Imitation vanilla flavor	4.0	4.0	4.0	Greinoman's/Unified Industries, Inc., Cumming, GA
Semi-sweet chocolate chips	275.0	275.0	275.0	Nestle USA, Inc. Culinary Division, Solon, OH
Large, Grade A egg	114.0	114.0	114.0	Kroger Corp., Cincinnati, OH
Salted butter	227.3	113.0	113.0	Land O Lakes, Inc., Arden Hills, MN
Dried plum puree	n/a	63.0	63.0	Sunsweet Growers, Inc., Yuba City, CA

[1] Procedure: Ingredients were mixed with a Kitchen Aid mixer (model K5SS, St. Joseph, MI) equipped with a paddle beater and baked in a rotary oven (National Manufacturing Co., Inc. Lincoln, NE) Flour, soda and salt were combined in a separate bowl. Butter, sugar, brown sugar, vanilla (and Sweet One®and dried plum puree when appropriate) were creamed at speed 1 for 1 minute. Beaten egg was added and mixed at speed 2 for 2 minutes. Dry ingredients were then added in three additions as the dough was mixed at speed 2 for 2 minutes. 17±1g of dough was scooped with a # 70 scoop and placed in 6 rows down and 3 across on a baking sheet (41.9 cm x 30.5 cm). Each pan was lined with parchment paper and lightly sprayed with Pam non-stick cooking spray (International Home Foods, Inc., Parsippany, NJ). Dough was gently flattened to the height of the chocolate chips, 0.8 cm (AACC 10-50D, 2000). Cookies were baked at 190ºC (375ºF) for 10 minutes.

replaced based on the following equivalency: 16.6 grams granulated sugar was replaced by 1 gram of Sweet One®.

Ingredient sources are found in **Tables 3.2** and **3.3**. Ingredients were from the same lot whenever possible. If multiple lots of a single ingredient were used, all lots were combined and aliquots drawn as needed. Eggs and butter, which were purchased weekly, were from the same lot within each purchase. Dry ingredients and butter were weighed one day in advance. Eggs and vanilla were measured on bake days. Eggs were thoroughly combined and aliquots taken for each formula. Eggs and butter were brought to room temperature for approximately 45 minutes prior to use.

Ingredients were combined according to the procedures presented in **Tables 3.2** and **3.3**. For both cookie types, ingredients were mixed with a Kitchen Aid mixer (Model K5SS, St. Joseph, MI) with a GraLab timer (Model 167, Centerville, OH) attached. Oatmeal cookies were prepared by combining all dry ingredients (including the ace-K/dextrose blend in the RFS formula) at speed 1 for 2 minutes. Eggs, shortening, butter, vanilla (and prune puree in the RF and RFS formulas) were added and mixed at speed 2 for 1 minute. Chocolate chip cookies were prepared by creaming butter (and prune puree in the RF and RFS formulas), vanilla, sugar and brown sugar (including the ace-K/dextrose blend in the RFS formula) for 1 minute at speed 1. Eggs were then added and mixed at speed 2 for 2 minutes. Dry ingredients were added in three additions while the dough was mixed for an additional two minutes at speed 2. Chocolate chips were then added and the dough was mixed for 30 seconds at speed 1.

After mixing, the dough was gently portioned with a #70 scoop, weighed, and deposited on two half-sheet pans (41.9 cm x 30.5 cm). Each half-sheet pan had been lined with parchment paper and lightly sprayed with Pam® non-stick cooking spray (International Home Foods, Inc., Parsippany, NJ) prior to depositing the dough. Oatmeal cookies were 15±1 g and chocolate chip cookies were 17±1 g. Oatmeal cookies were gently flattened, then rolled to 0.6 cm using wooden dough guides. Chocolate chip cookies were gently flattened to the height of the chocolate chips, 0.8 cm (AACC Method 10-50D 2000). Cookies were baked in a rotary oven (National Manufacturing Co., Lincoln, NE) to ensure uniform heat distribution. Reduced baking times are recommended in reduced-fat products to prevent over-drying (California Prune Board 1999). Full-fat oatmeal cookies were baked for 11 minutes and RF and RFS oatmeal cookies were baked for 9 minutes at 176°C. All chocolate chip cookie formulations were baked for 10 minutes at 190°C. After baking, cookies were cooled to room temperature on a wire rack for approximately one hour before any testing was conducted.

Storage Stability

Order of baking was randomized and all treatments within cookie type were prepared once for each day of data collection to eliminate variation due to multiple bakes. Barometric pressure was recorded on each bake day. After cookie spread was determined, cookies were sealed individually in 29.2 μm thick sandwich bags with a zipper-type closure (Kroger Corp., Cincinnati, OH) and stored in a single layer at room temperature (22.7±0.99ºC) for 1-7 days. This storage method was chosen because it closely replicates consumer home storage conditions. Temperature and humidity were recorded daily. Eighteen cookies from each treatment were assigned randomly for sensory data collection on days 1 and 3 or days 5 and 7. Ten cookies were randomly assigned to physicochemical/instrumental evaluation (probing and water activity) on corresponding days (1 and 3 or 5 and 7). The remaining 8 cookies were randomly assigned to the remaining two storage periods for physicochemical/instrumental evaluation. Therefore, instrumental data were collected from each batch of each replication of each treatment on each day of storage.

Color

Order of baking was randomized and all treatments within cookie type were prepared once for each day of data collection to eliminate variation due to multiple bakes. Each of the two pans prepared per cookie type were considered one replication. Four cookies from the center of each pan were randomly assigned to sensory evaluation and instrumental evaluation. The cookies were stored individually in 29.2 μm thick sandwich bags with a zipper-type closure (Kroger Corp., Cincinnati, OH) until evaluation, which was performed three days after baking.

Three of the four cookies from each pan (replication) were designated for evaluation by the color spectrophotometer and digital camera method (**Figure 3.1**). Because the tests conducted were not destructive, the same selected cookies were also used for visual sensory evaluations. Of the three cookies used for instrumental evaluation, one was randomly assigned for sensory evaluation in the Macbeth booth and one was randomly assigned for evaluation in the sensory booth. The fourth cookie was designated a spare and set aside in case one of the test cookies was damaged during evaluation.

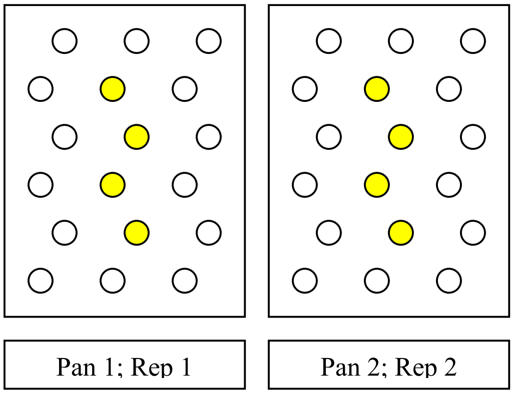

Figure 3.1. Representation of pans/replications obtained per batch of treatment. The four center cookies from each pan were randomly assigned to sensory and/or instrumental evaluation.

Storage

Physicochemical and Instrumental Techniques

Cookie Spread

Cookie spread was determined according to AACC method 10-50D (2000) on the day of baking. Six randomly selected cookies from each cookie formulation were used to determine the width, thickness and width-to-thickness ratio. Barometric pressure was used as a correction factor in cookie spread calculations. Cookie spread was repeated twice for each formulation per bake day. Cookie spread is a non-destructive procedure, and the cookies used for this test were used for subsequent sensory and instrumental evaluations.

Water Activity

Water activity was determined using an Aqua Lab water activity meter (Decagon Devices, Pulman, WA). This test was conducted on storage days 1, 3, 5 and 7. After probing was complete, the probed cookies were combined and ground to uniform particle size in a Cuisinart Mini-Prep Processor (model DLC-1, Cuisinart, East Windsor, NJ). Four aliquots were drawn from the composite samples as described by Curley and Hoseney (1984) for each cookie formulation for data collection for each of the six replications.

Puncture Testing

Puncture testing was conducted according to the method outlined by Bourne (1975, 1982) and Gaines and others (1992). Probing was conducted at the same time of day for each storage day. A 50-kg capacity TA.XT2 Texture Analyzer (Stable Micro Systems, Haselmere, Surrey, England) was used. The Texture Analyzer was equipped with a 0.3 cm probe and a baseplate with a 0.6 cm hole to accept the probe. The probe was set to move at 5 mm/second. Trigger force was 10 g. Cookies were punched completely through 9 times in an offset bull's-eye pattern as shown in **Figure 3.2**, avoiding the outer 15% of the cookie to avoid 'edge effects' (Gaines and others 1992). For each replication, 4-5 cookies per treatment per storage day were probed. Cookie height, time and force to yield point, time, force and area to peak height, area under the curve and slope were collected for analysis.

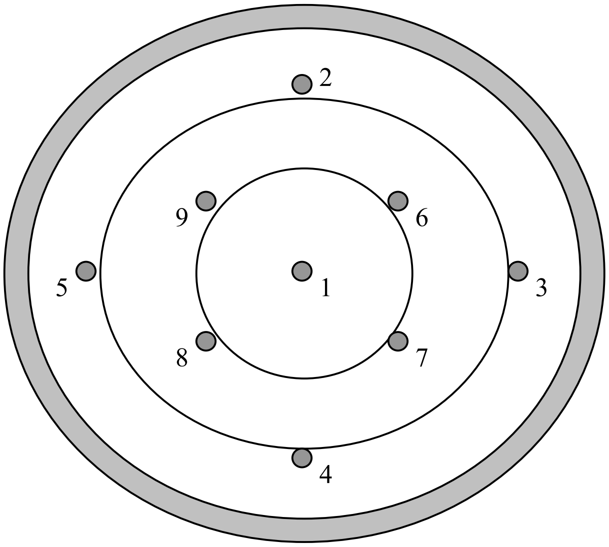

Figure 3.2. Representative probing pattern for oatmeal and chocolate chip cookies. Probe parameters were measured using a 50-kg capacity TA.XT2 Texture Analyzer equipped with Texture Expert, Version 1.20 (Stable Micro Systems, Haselmere, Surrey, England) and a 0.3 cm probe at a crossarm speed of 5 mm/s.

Sensory Evaluation

A trained sensory panel of 7-8 professional panelists from the USDA-ARS Sensory Lab at Russell Research Center (Athens, GA) performed sensory evaluation. Each panelist had been trained in all aspects of sensory analysis and had extensive testing experience using the Spectrum® approach to descriptive analysis (Meilgaard and others 1999). The panelists were also trained in using the Compusense computerized sensory analysis system (Compusense® *five*, release 4.0, Compusense, Inc., Quelph, Ontario, Canada).

The panelists had prior experience with texture and flavor attributes of these reduced-in-calorie oatmeal and chocolate chip cookies. During twelve 1-2 hour training sessions, panelists reviewed the texture and flavor attributes to be assessed, created a lexicon of terms and identified the specific attributes to be evaluated. Through training, panelists clarified the terminology used to evaluate all attributes and established references as anchor points for the line scales using Spectrum® method techniques (Meilgaard and others 1999). Attributes, terms and references are detailed in **Table 3.4.**

During sensory panel training, quantitative and qualitative data were analyzed to determine panelists' performance, appropriateness of terms in discriminating product differences, redundancy of terms and actual product differences (Powers 1984). Means and standard deviations were used to assess acceptable discriminating ability.

Panelists evaluated all treatments of both cookie types on storage days 1, 3, 5 and 7. Cookies from each formulation for one cookie type for storage days 1 and 5 or 3 and 7 were presented to panelists on the same day during the same session.

Table 3.4. Flavor and texture attributes, definitions[1] and references used by trained sensory panel to evaluate oatmeal and chocolate chip cookies.

<table>
<tr><th rowspan="2">Attribute</th><th colspan="2">Definition by cookie type</th><th>References/anchors
0--15</th></tr>
<tr><th>Oatmeal</th><th>Chocolate Chip</th><th>not perceptible high intensity</th></tr>
<tr><td colspan="4">-----------------------------------Flavor, mouthfeel and basic taste attributes-------------------------------------</td></tr>
<tr><td colspan="4">Phase I—Aromatic Flavor Notes</td></tr>
<tr><td>Cinnamon/woody spice</td><td>Aromatic associated with cinnamon and non-specific spices</td><td></td><td rowspan="10">The following was used as a universal scale which was applied to all flavor and afterfeel attributes:
• Soda note in saltine (2)
• Grape note in grape Kool-aid (5) and Welch's grape juice (10)
• Orange note in orange juice from concentrate (7) and Tang (9.5)
• Cinnamon note in Big Red gum (12)</td></tr>
<tr><td>Brown sugar (molasses)</td><td>Aromatic associated with brown sugar/molasses</td><td></td></tr>
<tr><td>Prune puree</td><td>Aromatic associated with prune puree</td><td></td></tr>
<tr><td>Grainy/oatmeal</td><td>Aromatic associated with non-specific grain/oatmeal</td><td></td></tr>
<tr><td>Brown sugar (caramelized)</td><td></td><td>Aromatic associated with brown sugar/caramelization</td></tr>
<tr><td>Chocolate</td><td></td><td>Aromatic associated with chocolate</td></tr>
<tr><td>White-wheat flour</td><td></td><td>Aromatic associated with white-wheat flour</td></tr>
<tr><td>Butter</td><td colspan="2">Aromatic associated with butter</td></tr>
<tr><td>Vanilla</td><td colspan="2">Aromatic associated with vanilla</td></tr>
<tr><td>Soda</td><td colspan="2">Aromatic associated with baking soda</td></tr>
</table>

Phase II—Basic Tastes		
Sweet	Basic taste on the tongue stimulated by sugars and high potency sweeteners	Sucrose solution in water 2% (2)---5% (5)---10%(10)---15% (15)
Salt	Basic taste on the tongue stimulated by sodium salt, especially sodium chloride	NaCl solution in water 0.2% (2.5)---0.35% (5)---0.5% (8.5)---0.7% (15)
Sour	Basic taste on the tongue stimulated by acids	Citric acid solution in water 0.05% (2)---0.08% (5)---0.15% (10)---0.2% (15)
Bitter	Basic taste on the tongue stimulated by solutions of caffeine, quinine and certain other alkaloids	Caffeine solution in water 0.05% (2)---0.08% (5)---0.15% (10)---0.2% (15)
Phase III—Afterfeel		
Astringency	Feeling of drying of the linings of the mouth	
---Texture attributes---		
Phase I—Evaluated by breaking with fingers		
Manual hardness	Manual force required to break or separate the sample into two pieces	Pringle (4) Ginger snap (10)
Manual fracturability	Force with which the sample breaks	Graham cracker (4) Ginger snap (8) Peanut brittle (13)
Phase II—Evaluated surface characteristics with lips		
Roughness	Amount of particles in the surface as detected by the lips	Gelatin (0) Pringle (8) Rye wafer (15)
Phase III—Evaluated at first bite with front teeth		
Oral fracturability	Force with which the sample breaks at the first bite with the front teeth	Graham cracker (4) Ginger snap (8) Peanut brittle (13)

Phase IV—Evaluated at first chew with molar teeth		
Cohesiveness	Degree to which the sample deforms rather than crumbles, cracks or breaks at first chew with molar teeth	Corn bread (1) Raisin (10) Chewing gum (15)
Oral hardness	Force required to bite through the sample at first chew with molar teeth	American cheese (4) Peanuts (9.5) Lifesavers (14.5)
Phase V—Evaluated during chewdown		
Oiliness	Amount of oil in the sample	Saltine (0) Tuna in oil (11)
Chewiness	Amount of work to chew the sample to the point of swallow	Rye bread (1.5) Gum drop (8.5) Tootsie Roll (13)
Phase VI—Evaluated after swallow		
Residual particles	Amount of particles in the mouth after swallowing	Nabisco Oatmeal Cookies (~5)
Oily mouthcoat	Amount of oily coating in the mouth after swallowing	Keebler Chips Deluxe Soft and Chewy (~5)

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[1] All flavor definitions were determined by the in-house panel (USDA-ARS, Sensory Evaluation Laboratory, Athens, GA). Basic taste definitions were obtained from Civille and Lyon (1996) and basic taste references were obtained from Meilgaard et al. (1999). All texture definitions and references were obtained from Meilgaard et al. (1999), except the references for manual hardness, manual fracturability and chewiness (in-house panel, USDA-ARS, Sensory Evaluation Laboratory, Athens, GA)

Panelists were seated in individual booths under low-pressure sodium vapor light (CML-18, Trimble House, Norcross, GA) to mask sample color differences. Jars of aromatic reference samples (**Tables 3.5** and **3.6**) were provided for use during evaluation. These references provided a consistent reminder of the aromatic flavor sensations being evaluated.

Table 3.5. Aromatic reference standards for oatmeal cookies[1].

Aromatic Sensation	Amount	Product Information
Cinnamon/woody spice[2][3]	0.3 g cinnamon/clove/ nutmeg mixture	Kroger Co., Cincinnati, OH
Brown sugar/molasses[3]	4.5 g light brown sugar	Kroger Co., Cincinnati, OH
Dried plum puree[3]	6.0 g dried plum puree	Sunsweet Growers, Inc., Yuba City, CA
Grainy/oatmeal[3]	6.5 g Old-fashioned oats	The Quaker Oats Co., Chicago, IL
Butter[4]	5.5 g salted butter	Land O Lakes, Inc., Arden Hills, MN
Vanilla[5]	5 drops imitation vanilla flavoring	Greinoman's/Unified Industries, Inc., Cumming, GA

[1] Each panelist received a set of reference standards. Each standard was held in a closed screw-top 3.5 oz. jar. Panelists opened and immediately closed the jars after sniffing as needed during product evaluation.

[2] Cinnamon/clove/nutmeg mixture was prepared according to the amounts specified in the oatmeal cookie formula.

[3] Samples were prepared once and used for each subsequent panel session.

[4] Samples were refrigerated. New samples were prepared after three storage days.

[5] Samples were prepared approximately one hour prior to each panel session. Cotton balls served as a carrier.

Table 3.6. Aromatic reference standards for chocolate chip cookies[1].

Aromatic Sensation	Amount	Product Information
Brown sugar/ caramelized[2]	4.5 g light brown sugar	Kroger Co., Cincinnati, OH
Chocolate[2]	18.0 g semi-sweet chocolate chips	Nestle USA, Inc. Culinary Division, Solon, OH
White wheat flour[2]	3.0 g all-purpose flour	Con Agra, Inc., Omaha, NE
Butter[3]	5.5 g salted butter	Land O Lakes, Inc., Arden Hills, MN
Vanilla[4]	5 drops imitation vanilla flavoring	Greinoman's/Unified Industries, Inc., Cumming, GA

[1] Each panelist received a set of reference standards. Each standard was held in a closed screw-top 3.5 oz. jar. Panelists opened and immediately closed the jars after sniffing as needed during product evaluation.

[2] Samples were prepared once and used for each subsequent panel session.

[3] Samples were refrigerated. New samples were prepared after three storage days.

[4] Samples were prepared approximately one hour prior to each panel session. Cotton balls served as a carrier.

A warm-up sample was provided to allow panel self-calibration. The control version of each cookie prepared with margarine was used as a warm-up, as it was most representative of the samples being evaluated. Cookies were coded with random 3-digit numbers and presented in balanced order to each panelist (Meilgaard and others 1999). Each panelist evaluated three cookies following the warm-up sample. After a 15 minute break, the remaining 3 samples were evaluated. Filtered water, unsalted soda crackers and apple slices were provided for palate cleansing.

Individual flavor and texture attributes (**Table 3.4**) were scored on 15-cm line scales using Compusense® computerized scorecard and sensory analysis program. The Compusense® system allowed each panelist to record their line scale responses while evaluating samples by positioning a cursor on the scale with a mouse. Data were collected by a central computer and downloaded for analysis. Panelists were also given the option to write additional comments about the samples; these comments were collected and analyzed for trends in conjunction with the line scale data.

Color

Sensory Evaluation

Panelist Selection

Eight-ten untrained but experienced panelists were utilized for the visual evalution using a Macbeth and sensory booth. The panelists had prior flavor and texture sensory experience and were familiar with the use of line scales. Prior to evaluation, panelists were screened (short method) using Ishihara's Tests for Colour-Blindness (38 Plates Edition, 1991, Kanehara & Co., Ltd. Tokyo, Japan). The order in which panelists were assigned to evaluate the samples in the Macbeth booth or sensory booth was randomized.

Development of physical references for sensory evaluation

Physical color reference cards were created to represent numerical anchors of 1, 3, 5, 7 and 9 on a 0-10 line scale, which represented the cookie color range from light to dark. Cookie references were first developed using the formulas presented in **Table 3.7**. The formulas were derived by modifying full-fat control and reduced-in-fat chocolate chip cookie basic dough formulations without the inclusion of chocolate chips. One pan of each of the 5 formulas was baked and CIELAB values were collected from 5 points on the cookie surface of the center cookie from each pan. These selected cookies were computer color-matched by Custom Color (Athens, GA) and latex paints (Wash'n Wear interior flat wall paint, Jones-Blair Company, Chattanooga, TN) were formulated. Color reference cards (**Figure 3.3**) were created by dipping 8-cm x 12-cm posterboard swatches in each paint. A 2.5-cm diameter circle was cut from the center of each swatch and paint was applied to the exposed edge of the circle. Swatches were dried completely in a desiccator. CIELAB values were collected from 4 positions on each swatch for comparison with original cookie reference. Average CIELAB values for the cookie references and physical references are presented in **Table 3.8**. Although the cookie and paint CIELAB values differ, three experimenters verified, under cool white fluorescent lighting, that the resulting physical color reference cards were good visual matches to the cookie samples. The physical color references also approximated the range of cookie color represented by the line scale.

Table 3.7. Formula and procedure[1] for reference cookies

		Corresponding line scale position				
Ingredients	Product information	1	3	5	7	9
		--(g)--	--(g)--	--(g)--	--(g)--	--(g)--
All-purpose flour	ConAgra, Inc., Omaha, NB	308.6	308.6	308.6	308.6	308.6
Salt	Flavor House, United Salt Corp., Houston TX	5.5	5.5	5.5	5.5	5.5
Baking soda	PYA/Monarch, Greenville, SC	3.0	3.0	3.0	3.0	3.0
Granulated sugar	Monarch Regency, Greenville, SC	259.0	150.0	150.0	150.0	
Light brown sugar	Domino Sugar Corp., NY, NY		109.0	109.0	109.0	
Dark brown sugar	Dixie Crystals, Savannah Foods and Industries, Savannah, GA					259.0
Imitation vanilla flavor	Greinoman's/Unified Industries, Inc., Cumming, GA	4.0	4.0	4.0	4.0	10
Large, Grade A egg	Kroger Corp., Cincinnati, OH	114.0	114.0	114.0	114.0	114.0
Salted butter	Land O Lakes, Inc., Arden Hills, MN	227.3	227.3	189.3	113.0	113.0
Dried plum puree	Sunsweet Growers, Inc., Yuba City, CA			21.0	63.0	63.0

[1] Ingredients were mixed with a KitchenAid Classic mixer (model K4555, St. Joseph, Mich.) equipped with a paddle beater and baked in a Maytag oven (model MER5530AAWW, Maytag Appliances, Cleveland, OH). Flour, salt and soda were combined in a separate bowl. Butter, sugar, brown sugar and vanilla (and prune puree where appropriate) were creamed at speed 1 for 1 minute. Beaten egg was added and mixed at speed 2 for 2 minutes. Dry ingredients were then added in 3 additions as the dough was mixed at speed 2 for 2 minutes. 17±1g of dough was scooped with a #70 scoop and placed in 6 rows down and three across on a baking sheet. Each pan was lined with parchment paper and sprayed with Pam non-stick cooking spray (International Home Foods Inc., Parsippany, NJ). Dough was gently flattened to approximately 6mm thickness and baked at 190C (375F) for 9 minutes. Cookies were cooled on the pan for 5 minutes, then removed to a wire rack to cool for at least 1 hour.

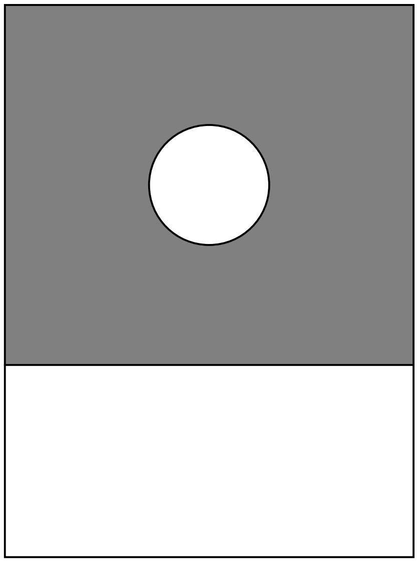

Figure 3.3. Representation of physical reference sample. Each swatch was 8-cm x 12-cm with a 2.54-cm hole to allow comparison with the cookie sample.

Table 3.8. Average CIELAB values of reference cookie samples[1] and resultant physical[2] references and RGB and CIELAB values of digital[3] references

	Reference Cookies			Physical References			Digital References					
	L*	a*	b*	L*	a*	b*	R	G	B	L*	a*	b*
Reference 1	77.90	5.93	27.64	82.24	4.99	25.29	255	241	139	94	-5	51
Reference 3	72.37	9.45	30.78	77.79	8.97	31.22	253	232	126	91	-2	54
Reference 5	58.96	14.49	33.71	60.66	11.03	30.64	202	172	79	71	3	53
Reference 7	52.04	16.22	33.59	52.41	11.57	29.38	192	156	36	65	5	67
Reference 9	40.10	16.42	25.77	44.22	12.64	23.08	168	131	58	57	8	47

[1] Cookie formulations presented in Table 3.7; CIELAB values were collected from 5 points on the cookie surface of the center cookie from each pan. Cookies were computer color-matched by Custom Color (Athens, GA) for development of latex paints used in the creation of physical references.

[2] Physical references were created by dipping 8-cm x 12-cm posterboard swatches in each paint created from the reference cookies. A 2.5-cm diameter circle was cut from the center of each swatch. CIELAB values were collected from 4 positions on each swatch for comparison with original cookie reference.

[3] Digital color references were created in Adobe PhotoShop 5.5 (Adobe Systems Inc., San Jose, CA) using RGB mode. A 1-in. x 1-in. circle was created using the Elliptical Marquee tool. Circle color was adjusted using the Color Picker, using the CIELAB values obtained from spectrophotometric measurement of the physical references as a starting point. The Color Picker selection circle was moved in the RGB color space until a visual color match was obtained between the physical reference sample and onscreen image. Final adjustments to lightness/darkness were made in the LAB color space. RGB and LAB values were recorded for each of the 5 reference colors.

Macbeth SpectraLight II Light Booth Evaluation

One at a time, panelists were seated in front of the Macbeth booth, approximately 60 cm from the cookie surface. There was no illumination in the room other than that from the light booth. The cool white setting (color temperature 4,150K) was used. A stand, covered with a 12.5-cm x 2-cm poster board card painted Munsell N/7 Standard (Sherwin Williams Latex SW1005Sylverado) to match the booth interior, was positioned at the center back of the booth interior. The stand allowed the sample to be positioned at an approximate 45° angle to the light source and an approximate 90° angle to the panelists.

The cookies were presented in random order and evaluated monadically. Panelists were given a paper ballot with a 0-10 point line scale for each sample. Physical references cards described previously represented 1, 3, 5, 7 and 9 on the line scale and were placed before the panelists. Panelists held the reference cards over the cookie, viewing the center of the cookie through the 2.5-cm hole in the reference card. The panelist's color response was recorded on the line scale on the paper ballot.

Development of digital color references for sensory evaluation

Digital color references were created to represent 1, 3, 5, 7 and 9 on a 0-10 line scale, which represented the cookie color range from light to dark. The goal was to visually match both cookie and physical color reference cards. A Pentium III PC, 750 MHz, 64 MBRam with a ViewPanel VP150 (ViewSonic, Walnut, CA) monitor, equipped with a Magnum Xpert 128 videocard (ATI Technologies, Thornhill, ON, Canada) was used. The monitor was calibrated using Adobe Gamma protocol (Adobe Photoshop 5.5, Adobe Systems Inc., San Jose, CA).

To create each digital color reference, a new file was opened in Adobe Photoshop 5.5 (Adobe Systems Inc., San Jose, CA) using RGB mode. A 2.5-cm circle was created using the Elliptical Marquee tool. CIELAB values obtained from spectrophotometric measurement of the physical reference cards were entered as a starting point to add color to the circle. The Color Picker selection circle was moved in the RGB color space until a good visual color match as assessed by three experimenters was obtained between the physical reference card and onscreen image. Final adjustments to lightness/darkness were made in the LAB color space. In this manner, the 5 digital color references were created and RGB and LAB values were recorded for each. These values are presented in Table 3.8. Each circle was saved as an individual .bmp file, Windows format, resolution 300 pixels/inch.

The next step was to place the digital references into the computer questionnaire for presentation in the sensory booth. Using Compusense (Compusense® *five*, release 4.0, Compusense, Inc., Quelph, Ontario, Canada), the project was opened on the analyst workstation and the individual .bmp files were opened in the Title and Text area (image aspect ratio 50), Question area (image aspect ratio 25) and Instructions area (image aspect ratio 75). In the Title and Text area and Question area, the circles were spaced to align with 1, 3, 5, 7 and 9 on the line scale. Compusense background for all screens was changed to a gray similar to the Munsell N/7 Neutral background used in the Macbeth booth. The background for the individual reference circles was adjusted to match using side-by-side visual monitor comparison of Compusense and Photoshop images. To accomplish this, two monitors were attached to one computer via two matching video cards.

Sensory Booth Evaluation

A single sensory booth was used for evaluation in order to control lighting conditions. The sensory booth was approximately 80-cm wide by 51-cm deep, with its own ceiling. The booth counter was approximately 81-cm high. The testing room was lit by three ceiling fluorescent fixtures. The fixture directly behind the booth used for evaluation held 4 cool Sylvania F40 Cool White, 40W fluorescent lamps (Phillips Lighting Company, Somerset, NJ) each. The two other fixtures in the testing room, to the right and left of the booth, each held 2 Sylvania F40 Cool White, 40W fluorescent lamps. Additionally, a portable fixture that held 1 cool white lamp (GE Under Cabinet 21” Fluorescent Light Fixture, GE Home Electric Products, Cleveland, OH) was suspended from the ceiling of the booth directly above the evaluation area, approximately

105-cm from the booth counter. The combination of light fixtures provided approximately 100 foot-candles of light in the comparison area immediately in front of the monitor. Because the color of the digital images on the monitor varied depending on the angle of the viewer to the screen, a weight was suspended from the ceiling of the booth at the optimum eye-level. Under supervision of the panel leader, each panelist adjusted his/her chair until his/her eyes were at this viewing level.

Panelists were seated one at a time at a sensory booth equipped with the Compusense computerized sensory analysis system (Compusense® *five*, release 4.0, Compusense, Inc., Quelph, Ontario, Canada). Panelists were presented with a 0-10 line scale on the monitor. Cookies were evaluated monadically. To evaluate cookie color, the panelist held a cookie sample up to the screen and compared it with on-screen reference color circles that represented 1, 3, 5, 7 and 9 on the line scale. Panelists also had the option of viewing larger circles on the separate Instruction screen. The color intensity value for each cookie was marked on the computer line scale with a mouse input device. Order in which cookies were evaluated was randomized.

Instrumental Techniques

Color Spectrophotometer

A handheld Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ) was used to collect L*a*b* values from the three selected cookies from each formulation. The d/8 spherical geometry of the color spectrophotometer provides for measurement with or without the specular (gloss) component included. Including the specular component is particularly useful when comparing objects with different textures (Mabon 1993). Because the cookies were of relatively uniform texture, the specular component was excluded. Although the cookies used in this study were relatively small (averaging 6 cm in diameter), when viewed at the distance that a consumer may typically inspect the appearance, they would occupy over 4 degrees of the field of view. Therefore, the 10-degree observer function, appropriate for viewing angles over 4 degrees, was used.

Prior to use, the spectrophotometer was calibrated using the Minolta white calibration standard (CM-A70). CIELAB values were collected using the Illuminant F6 (cool white fluorescent, color temperature 4,150 K) setting. L*, a* and b* values were collected at two points on the cookie surface (**Figure 3.4**) and averaged to provide one L*, a* and b* value each per cookie. At each measurement point, the instrument took five readings and averaged the three most similar readings. Hue angle (*arctan [b*/a*]*) was calculated from the measurements.

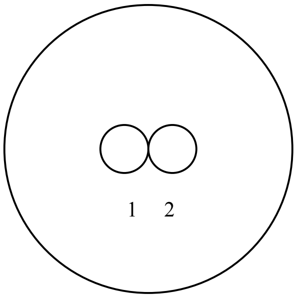

Figure 3.4. The spectrophotometer was used to collect CIELAB values from the two data points as represented above. The two values were then averaged to obtain single L*, a* and b* values for each cookie. Hue angle (arctan[b*/a*]) was calculated.

Digital Camera/Software

CIELAB values for the three selected cookies from each formulation were also determined using a modified version of the digital camera technique described by Papadakis and others (2000). A Macbeth SpectraLight II (Macbeth, Kollmorgen Instrument Corp., New Windsor, NY) light booth was used to provide cool white fluorescent illumination (color temperature 4,150 K). The booth was located in a room that could be darkened completely to avoid interference from ambient lighting. An Olympus 3000ZOOM (Olympus America Inc., Melville, NY) digital camera was positioned on a small tripod, approximately 25 cm from the sample. A stand, covered with a 12.5-cm x 20-cm posterboard card painted Munsell N/7 Standard (Sherwin Williams Latex SW1005Sylverado) to match the booth interior, was positioned at the center back of the booth interior. The stand allowed the sample to be positioned at an approximate 45° angle to the light source and an approximate 90° angle to the camera lens.

The digital camera was set to aperture f5.6, which was the setting derived from a previous study of hamburger color under the same lighting conditions with a 35 mm camera (Lyon 1998). The automatic shutter speed setting used by Papadakis and others (2000) allowed the camera to make automatic adjustments based on ambient lighting. In this study, a shutter speed of 1/20s was used to avoid any adjustments by the camera. No flash was used. White balance was set to fluorescent. The macro setting was used. Images were saved as uncompressed .tif files, 1600 x 1200 pixels.

To collect the images, the room was darkened. An image of the gray background was taken before and after the cookie photos as a self-check. One image of each cookie was recorded. Five images were collected per disk and the .tif files were downloaded to a PC using SanDisk software (SanDisk Corp., Sunnyvale, CA). The PC was equipped with a Pentium® II Processor with MMX technology, 400 MHz processor speed and 192.0 MB RAM.

The downloaded .tif files were opened in Adobe Photoshop 6.0 (Adobe Systems Inc., San Jose, CA). The images were cropped to exclude areas beyond the width and height of the cookie using the Crop Tool. Resolution for all images was 72 pixels/inch. In order to resize the image, sample width was measured. Using the Image Size menu, the sample width was entered with the Constrained Proportion option activated. Once resized, the Elliptical Marquee Tool was used to select a 2.5-cm diameter circle from the center of the cookie image. This selected area was copied to a new file and displayed in LAB mode (the asterisks are dropped from CIELAB terminology in Photoshop). The Magic Wand tool was used to select the white background, and then the Select Inverse function was used to select the cookie area. The histogram, which graphically depicted the number of pixels at each color level, gave the mean and standard deviation of color levels displayed for L*, a* and b* separately. The means and standard deviations were recorded. The following equations, adapted from Papadakis and others (2000), were used to convert the mean color levels obtained from the histograms from the 256 color levels used by the software to equivalent L*, a* and b* values.

- $L^* = (L/255)(100)$
- $a^* = (240a/255)-120$
- $b^* = (240b/255)-120$

L* ranges from 0 (black) to 100 (white). Photoshop specifies the possible range of values of a* and b* to be –120 to 120, although in theory a* and b* have no boundaries. These equations convert the 256 color levels used by the software to equivalent L*, a* and b* values. Hue angle (*arctan [b*/a*]*) was calculated from the measurements.

Statistical Analysis

Results of all sensory, physicochemical and instrumental tests were analyzed using SAS software (SAS for Windows, version 6.12, SAS Inc., Cary, NC). PROC UNIVARIATE was used to produce normality plots for the purpose of verifying normal distribution of data and equal variance. If the data lacked either variance equality or normality, it was transformed to meet the assumptions necessary for valid analysis (Cochran and Cox 1957). Mixed model of analysis of variance (PROC MIXED) was used ($p<0.05$) to compare treatments. Least-square means (LS MEANS) and standard error were generated. PDIFF was used for means separation (Littell and others 1996). T-tests (PROC TTEST) were performed to compare the Macbeth evaluation method to the sensory booth method and to compare the results obtained from the color spectrophotometer to those obtained with the digital camera/software method ($p<0.05$). Relationship between sensory and instrumental data was analyzed (PROC CORR) with the Pearson's Product Moment correlation statistic ($p<0.01$).

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CHAPTER IV

EFFECTS OF FAT AND SUGAR REDUCTION ON SHELF STABILITY OF OATMEAL AND CHOCOLATE CHIP COOKIES: SENSORY ATTRIBUTES AND INSTRUMENTAL PARAMETERS

Abstract

Three formulations of two cookie types were prepared using a non-sucrose sweetener blend (dextrose/acesulfame-K) and/or prune puree to replace 50% of the sugar and/or fat, respectively. Flavor and texture attributes were profiled 1, 3, 5 and 7 days post-bake by a trained sensory panel. Texture was assessed 1, 3, 5 and 7 days post-bake using physical and physicochemical techniques including probing and water activity. Data were analyzed with PROC MIXED and PDIFF ($p<0.05$). Relationships between sensory and instrumental assessments were identified using PROC CORR ($p<0.01$). Sugar and/or fat reduction minimally affected sensory characteristics over the storage period. Probe results indicated more textural changes in the oatmeal than chocolate chip formulations over time. Manual hardness and fracturability and oral fracturability were significantly correlated with all probe parameters reported for the oatmeal formulations. Few significant correlations between instrumental and sensory results were found for the chocolate chip formulations.

Introduction

Eighty-seven percent of consumers surveyed in 2000 by the Calorie Control Council regularly chose lighter versions of their favorite foods (CCC 2000). Consumers who used some reduced-fat and some full-fat products had better overall micronutrient profiles (Petersen et al. 1999). Despite the benefits of fat-reduced products, reducing overall calorie intake (both fat and carbohydrates) may be a more effective weight loss strategy. Harvey-Berino (1998) found that moderately obese subjects on energy-restricted diets lost significantly more weight than those on fat-restricted diets for a 24-week period. Both studies point to the need for reduced-fat and reduced-calorie products that consumers find acceptable and desirable.

Additionally, an increasing number of ingredients, like dried plum puree and acesulfame-K, are being marketed to consumers with recommendations to facilitate consumer production of modified baked products. While several studies have demonstrated the impact of these products on flavor, texture and acceptability (Perry 2001, Swanson and Munsayac 1999, Redlinger and Setser 1987, Bullock et al. 1992), little is known about their effect on shelf life of the resultant products.

Shelf life is the amount of time required before a product exhibits unacceptable physical, chemical, microbiological or sensory characteristics (Gacula 1975). The staling process is one component of shelf life, and is described as the progressive non-microbial deterioration of quality of baked products resulting in decreased consumer acceptance. The consumer determines the degree of staleness, and therefore acceptability, based on smell, taste, touch and appearance (Bechtel et al. 1953).

In relatively high-moisture baked products like bread, staling is primarily due to starch retrogradation, moisture loss and loss of crumb cohesion (Cauvain 1999). However, there is little information regarding shelf-stability and staling processes of cookies and other low-moisture baked goods. Cookies are generally high in fat at 30-

60% on a flour-weight-basis (fwb) and high in sugar (30-75% fwb) with a low moisture content (7-20% fwb) (Pyler 1988). Because the starch in cookies is not gelatinized due to limited water availability, retrogradation does not play a major role in cookie staling. The recrystallization of sugar and associated changes in water distribution, however, may cause texture and flavor changes in cookies during storage (Given 1993, Hoseney 1986). Fats in baked goods slow moisture migration and therefore retard staling (Hegenbart 1993). The stability of fats and flavorings used may also affect cookie staling (Pyler 1988). Over time, the flavor-binding and release properties of fat may change (Given 1993), and oxidation of fats can contribute to the development of off-flavors and changes in product aroma (Love 1992).

Cookies and other low-moisture baked goods generally have a water activity around 0.30 and are not susceptible to microbial proliferation. An increase in water activity can increase the potential for microbial growth and produce a soggy texture (Fontana 2000). Changes in water activity over time can impact the rate of non-enzymatic browning reactions and lipid oxidation reactions, both of which can affect cookie flavor.

Partial replacement of fat and sugar in the cookie system may further affect staling properties. In cookies, fat contributes to aeration, lubrication, tenderness and overall eating quality (Hegenbart 1993, 1995). In addition to contributing flavor, fat carries fat-soluble flavors and regulates flavor release (Drewnowski 1992). In the absence of fat, fat-soluble flavors are released all at once, resulting in reduced flavor sensation (Setser and Racette 1992; Plug and Haring 1993) or a perception of intense flavor that quickly disappears (Plug and Haring 1993). Reducing or replacing fat can change the flavor profile and increase the perception of off-flavors. The moisture-control ability of a fat-replacer is particularly important to shelf life (Hegenbart 1995). Prune puree has been used successfully as a partial fat replacer in reduced-in-fat and reduced-in-fat and sugar cookies (Swanson and Munsayac 1999, Perry 2001). Prune puree contains soluble and insoluble pectins and malic acid, which trap flavor components and release them slowly during mastication. Prune puree also contains 15% sorbitol, which acts as a humectant (California Prune Board 1999a) and may extend the shelf life of baked goods by holding moisture in the product.

Sugar provides sweetness and flavor, and helps develop the characteristic crisp, brittle texture of cookies (Davis 1995). Sugar also contributes to tenderness by inhibiting starch gelatinization and gluten formation. A high-intensity sweetener blend of Ace-K and dextrose (Sweet One®, Stadt Corporation, Brooklyn, NY) has been used successfully in conjunction with prune puree as a partial sugar replacer in cookies (Perry 2001). The recrystallization of the remaining sucrose may be affected by the humectant properties of prune puree and dextrose and may in turn affect the water activity, flavor and texture of the cookies.

Sensory evaluation has been used to assess flavor and texture attributes of cookies (Armbrister and Setser 1994, Perry 2001) and texture has been assessed using both sensory and instrumental evaluation (Armbrister and Setser 1994, Gaines et al. 1992, Perry 2001, Swanson et al. 1999). Because staling is defined by consumer sensory evaluation of a product, sensory analysis is vital to detecting and identifying changes in a product over time. However, it may be possible to detect some of the textural changes that accompany staling instrumentally and correlate them to sensory evaluation results.

A valid method of instrumental evaluation of texture would reduce some of the time and expense associated with sensory evaluation (Meilgaard et al. 1999).

Traditionally, instrumental methods to assess cookie texture have been limited to the three-point beam test. This test, which involves supporting a sample on two beams and lowering a third beam down between the support beams until the sample breaks (Bourne 1982), measures the deformation (bend) of the sample and the force when the sample breaks (snap). This test may be inappropriate for softer, chewy cookies, which tend to bend rather than break when subjected to this test. Probing has been suggested as an alternative method of texture evaluation (Gaines et al. 1992, Gaines 1994) and has been used successfully with chewy products, such as bagels and fig bars (Johnson 1992). Probing measures the force required to press a cylindrical probe into and/or through a food sample (Bourne 1975). The test requires less product and provides better estimates of within-cookie variation when compared to the three-point break technique. Peak force measurements obtained by probing can be interpreted to indicate cookie hardness (Armbrister and Setser 1994, Gaines et al. 1992). Perry (2001) investigated the relationship between probing and trained sensory panel results for reduced-in-fat and reduced-fat and sugar cookies and found that area under the curve, rather than peak force, was the best indicator of cookie texture and predicted oral hardness, chewiness and cohesiveness.

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

Materials and Methods

Materials

Control (FFC), reduced-in-fat (RF) and reduced-in-fat and sugar (RFS) chocolate chip (CC) and oatmeal (OAT) formulations were prepared (**Tables 4.1 and 4.2**). Added sugar and/or fat were reduced by 50% where appropriate. RF and RFS cookies contained prune puree (Sunsweet Growers, Inc., Yuba City, CA) and RFS cookies were formulated with an alternative sweetener blend of acesulfame-K and dextrose (Sweet One®, Stadt Corp., Brooklyn, NY).

In both cookie types, variable ingredients included granulated sugar, alternative sweetener blend, butter and prune puree. Shortening also varied in the OAT cookies. Sugar and fat substitutions were made according to manufacturer's recommendations (Sweet One® 1998, CPB 1999ab).

Preparation Methods

Dry ingredients were weighed 1 day in advance. Eggs and vanilla were measured on the day of baking. All ingredients, except eggs and butter, were purchased at the beginning of the study. Ingredients were from the same lot whenever possible; if multiple lots of a single ingredient were used, all lots were combined and aliquots drawn as needed. Eggs and butter were purchased from the same lot weekly. Prior to mixing, eggs and butter were held at room temperature for 45 minutes.

All cookies were mixed in a Kitchen Aid mixer (model K5SS, St. Joseph, MI) and baked in a rotary oven (National Manufacturing Co. Inc., Lincoln, NE). After cooling for

1 hr, cookies were sealed individually in 29.2 μm thick sandwich bags with a zipper-type closure (Kroger Corp., Cincinnati, OH) and stored in a single layer at room temperature (22.7±0.99 C) for 1-7 days.

Table 4.1—Formula and Procedure[1] for Chocolate Chip Cookies

Ingredients	Control (g)	Reduced Fat (g)	Reduced Fat & Sugar (g)	Product Information
All-purpose flour	308.6	308.6	308.6	Con Agra, Inc., Omaha, NE
Granulated sugar	150.0	150.0	75.0	Monarch Regency, Greenville, SC
Sweet One®	n/a	n/a	4.5	Stadt Corp. Brooklyn, NY
Light brown sugar	109.0	109.0	109.0	Dixie Crystals, Diamond Crystal Brands, Inc, Savannah, GA
Baking soda	3.0	3.0	3.0	PYA/Monarch, Inc., Greenville, SC
Iodized Salt	5.5	5.5	5.5	Flavor House, United Salt Corp., Houston, TX
Imitation vanilla flavor	4.0	4.0	4.0	Greinoman's/Unified Industries, Inc., Cumming, GA
Semi-sweet chocolate chips	275.0	275.0	275.0	Nestle USA, Inc. Culinary Division, Solon, OH
Large, Grade A egg	114.0	114.0	114.0	Kroger Corp., Cincinnati, OH
Salted butter	227.3	113.0	113.0	Land O Lakes, Inc., Arden Hills, MN
Dried plum puree	n/a	63.0	63.0	Sunsweet Growers, Inc., Yuba City, CA

[1] Procedure: Ingredients were mixed with a Kitchen Aid mixer (model K5SS, St. Joseph, MI) equipped with a paddle beater and baked in a rotary oven (National Manufacturing Co., Inc. Lincoln, NE) Flour, soda and salt were combined in a separate bowl. Butter, sugar, brown sugar, vanilla (and Sweet One®and dried plum puree when appropriate) were creamed at speed 1 for 1 minute. Beaten egg was added and mixed at speed 2 for 2 minutes. Dry ingredients were then added in three additions as the dough was mixed at speed 2 for 2 minutes. 17±1g of dough was scooped with a # 70 scoop and placed in 6 rows down and 3 across on a baking sheet (41.9 cm x 30.5 cm). Each pan was lined with parchment paper and lightly sprayed with Pam non-stick cooking spray (International Home Foods, Inc., Parsippany, NJ). Dough was gently flattened to the height of the chocolate chips, 0.8 cm (AACC 10-50D, 2000). Cookies were baked at 190ºC (375ºF) for 10 minutes.

Table 4.2—Formula and Procedure[1] for Oatmeal Cookies

Ingredients	**Control (g)**	**Reduced Fat (g)**	**Reduced Fat & Sugar (g)**	**Product Information**
All-purpose flour	222.6	222.6	222.6	Con Agra, Inc., Omaha, NE
Old fashioned oats	160.0	160.0	160.0	The Quaker Oats Co., Chicago, IL
Granulated sugar	100.0	100.0	50.0	Monarch Regency, Greenville, SC
Sweet One®	n/a	n/a	3.0	Stadt Corp. Brooklyn, NY
Light brown sugar	165.0	165.0	165.0	Dixie Crystals, Diamond Crystal Brands, Inc, Savannah, GA
Baking soda	3.0	3.0	3.0	PYA/Monarch, Inc., Greenville, SC
Iodized salt	2.8	2.8	2.8	Flavor House, United Salt Corp., Houston, TX
Ground cinnamon	1.1	1.1	1.1	Kroger Corp., Cincinnati, OH
Ground cloves	0.3	0.3	0.3	Kroger Corp., Cincinnati, OH
Ground nutmeg	0.6	0.6	0.6	Kroger Corp., Cincinnati, OH
Imitation vanilla flavor	2.0	2.0	2.0	Greinoman's/Unified Industries, Inc., Cumming, GA
Large, Grade A egg	85.0	85.0	85.0	Kroger Corp., Cincinnati, OH
Vegetable shortening	125.0	62.5	62.5	Crisco, Proctor & Gamble, Cincinnati, OH
Salted butter	104.0	52.0	52.0	Land O Lakes, Inc., Arden Hills, MN
Dried plum puree	n/a	61.0	61.0	Sunsweet Growers, Inc., Yuba City, CA

[1] Procedure: Ingredients were mixed with a Kitchen Aid mixer (model K5SS, St. Joseph, MI) equipped with a paddle beater and baked in a rotary oven (National Manufacturing Co., Inc. Lincoln, NE). Flour, soda, salt, oats, sugar, brown sugar, cinnamon, cloves, nutmeg (and Sweet One® when appropriate) were blended in a mixing bowl at speed 1 for 2 minutes. Shortening, butter, eggs, and vanilla (and dried plum puree when appropriate) were added and mixed at speed 2 for 1 minute. 15±1g of dough was scooped with a #70 scoop. Dough was placed in 6 rows down and 3 across on a baking sheet (41.9 cm x 30.5 cm). Each pan was lined with parchment paper and lightly sprayed with Pam non-stick cooking spray (International Home Foods, Inc., Parsippany, NJ). Dough was rolled to 0.6 cm thickness (AACC 10-50D, 2000). Reduced-in-fat and reduced-in-fat-and-sugar cookies were baked at 176ºC (350ºF) for 9 minutes; full-fat control cookies were baked for 11 minutes.

Physical/Physicochemical Measurements

Cookie spread (AACC 10-50D 2000) was determined in duplicate for each treatment on the day of baking. Water activity was determined at storage days 1, 3, 5 and 7. Four aliquots were drawn from the composite samples as described by Curley and Hoseney (1984) for each cookie formulation; water activity was measured with the Aqua Lab device (Decagon Devices, Pullman, WA).

Cookies were probed (Bourne 1975, Bourne 1999, Gaines et al. 1992) on storage days 1, 3, 5 and 7 with a 50-kg capacity TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, England), equipped with Texture Expert Exceed software (version 2.13, Stable Micro Systems, Haselmere, Surrey, England). Trigger force was 10 g and a crossarm speed of 5 mm/sec was used. Cookies were placed on an aluminum plate 1.3-cm thick with a 0.6-cm diameter hole that accepted the 0.3-cm probe as it punched completely through the product at a travel distance of 25 mm. Cookies were probed in nine locations forming an offset bull's-eye pattern **(Figure 4.1)**. To avoid edge effects, the outer 15% of the cookie was not probed (Gaines et al. 1992). A single probe provided a force/time curve **(Figure 4.2)** from which the following parameters were obtained: area to first peak (A1), force to first peak (F1) and slope to first peak (S1), area to maximum peak (AMP) and force to maximum peak (FMP), average slope (AS) and sample height. Average slope is the average of all positive slopes from the initial detection of 10 g force through the entire thickness of the cookie. Four or five cookies per treatment per replication were probed.

Descriptive Sensory Analysis

Cookies were evaluated by an 8-member sensory descriptive panel from the USDA-ARS Sensory Laboratory, Russell Research Center, Athens, GA. The panel had extensive prior training and experience using descriptive analysis (Spectrum Method®, Meilgaard et al. 1999). In this study, panelists participated in additional training sessions to identify product attributes, clarify reference terminology and establish references as anchor points for flavor and texture attribute intensity levels **(Table 4.3)**. During training, quantitative and qualitative data were analyzed to determine panelists' performance, appropriateness of terms in discriminating product differences, redundancy of terms and actual product differences (Powers 1984). Means and standard deviations were used to

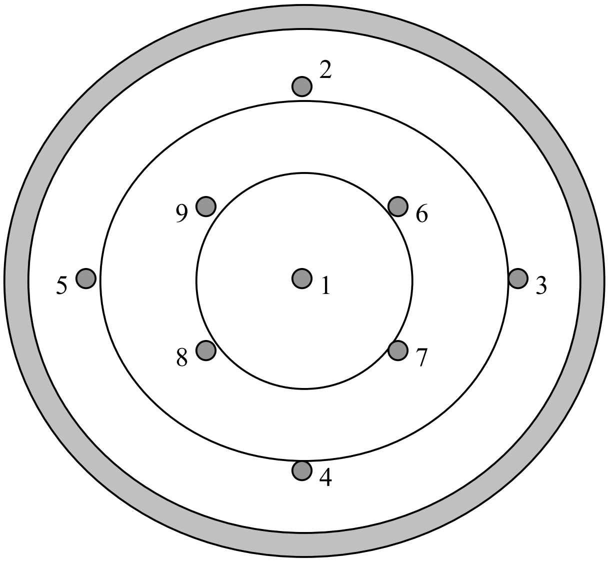

Figure 4.1. Representative probing pattern for oatmeal and chocolate chip cookies. Probe parameters were measured using a 50-kg capacity TA.XT2 Texture Analyzer equipped with Texture Expert Exceed, Version 2.13 (Stable Micro Systems, Haselmere, Surrey, England) and a 0.3 cm probe at a crossarm speed of 5 mm/s.

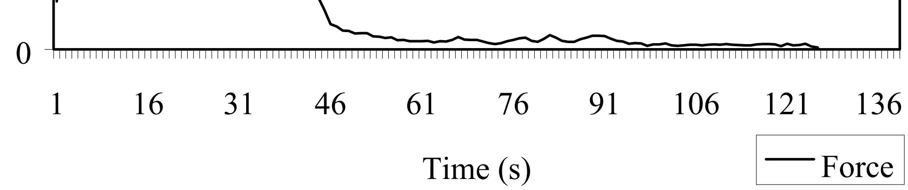

Figure 4.2 Typical force/time curve obtained from probing an RS cookie. Area, force and slope to 1st peak, area and force to maximum peak, and average slope were collected.

Table 4.3. Flavor and texture attributes, definitions[1] and references used by trained sensory panel to evaluate oatmeal and chocolate chip cookies.

<table>
<tr><th rowspan="2">Attribute</th><th colspan="2">Definition by cookie type</th><th>References/anchors
0---15</th></tr>
<tr><th>Oatmeal</th><th>Chocolate Chip</th><th>not perceptible high intensity</th></tr>
<tr><td colspan="4">-----------------------------------Flavor, mouthfeel and basic taste attributes------------------------------------</td></tr>
<tr><td colspan="4">Phase I—Aromatic Flavor Notes</td></tr>
<tr><td>Cinnamon/woody spice</td><td>Aromatic associated with cinnamon and non-specific spices</td><td></td><td>The following was used as a universal scale which was applied to all flavor and afterfeel attributes:
• Soda note in saltine (2)
• Grape note in grape Kool-aid (5) and Welch’s grape juice (10)
• Orange note in orange juice from concentrate (7) and Tang (9.5)
• Cinnamon note in Big Red gum (12)</td></tr>
<tr><td>Brown sugar (molasses)</td><td>Aromatic associated with brown sugar/molasses</td><td></td><td></td></tr>
<tr><td>Prune puree</td><td>Aromatic associated with prune puree</td><td></td><td></td></tr>
<tr><td>Grainy/oatmeal</td><td>Aromatic associated with non-specific grain/oatmeal</td><td></td><td></td></tr>
<tr><td>Brown sugar (caramelized)</td><td></td><td>Aromatic associated with brown sugar/caramelization</td><td></td></tr>
<tr><td>Chocolate</td><td></td><td>Aromatic associated with chocolate</td><td></td></tr>
<tr><td>White-wheat flour</td><td></td><td>Aromatic associated with white-wheat flour</td><td></td></tr>
<tr><td>Butter</td><td colspan="2">Aromatic associated with butter</td><td></td></tr>
<tr><td>Vanilla</td><td colspan="2">Aromatic associated with vanilla</td><td></td></tr>
<tr><td>Soda</td><td colspan="2">Aromatic associated with baking soda</td><td></td></tr>
</table>

Phase II—Basic Tastes		
Sweet	Basic taste on the tongue stimulated by sugars and high potency sweeteners	Sucrose solution in water 2% (2)---5% (5)---10%(10)---15% (15)
Salt	Basic taste on the tongue stimulated by sodium salt, especially sodium chloride	NaCl solution in water 0.2% (2.5)---0.35% (5)---0.5% (8.5)---0.7% (15)
Sour	Basic taste on the tongue stimulated by acids	Citric acid solution in water 0.05% (2)---0.08% (5)---0.15% (10)---0.2% (15)
Bitter	Basic taste on the tongue stimulated by solutions of caffeine, quinine and certain other alkaloids	Caffeine solution in water 0.05% (2)---0.08% (5)---0.15% (10)---0.2% (15)
Phase III—Afterfeel		
Astringency	Feeling of drying of the linings of the mouth	
	--Texture attributes---	
Phase I—Evaluated by breaking with fingers		
Manual hardness	Manual force required to break or separate the sample into two pieces	Pringle (4) Ginger snap (10)
Manual fracturability	Force with which the sample breaks	Graham cracker (4) Ginger snap (8) Peanut brittle (13)
Phase II—Evaluated surface characteristics with lips		
Roughness	Amount of particles in the surface as detected by the lips	Gelatin (0) Pringle (8) Rye wafer (15)
Phase III—Evaluated at first bite with front teeth		
Oral fracturability	Force with which the sample breaks at the first bite with the front teeth	Graham cracker (4) Ginger snap (8) Peanut brittle (13)

Phase IV—Evaluated at first chew with molar teeth		
Cohesiveness	Degree to which the sample deforms rather than crumbles, cracks or breaks at first chew with molar teeth	Corn bread (1) Raisin (10) Chewing gum (15)
Oral hardness	Force required to bite through the sample at first chew with molar teeth	American cheese (4) Peanuts (9.5) Lifesavers (14.5)
Phase V—Evaluated during chewdown		
Oiliness	Amount of oil in the sample	Saltine (0) Tuna in oil (11)
Chewiness	Amount of work to chew the sample to the point of swallow	Rye bread (1.5) Gum drop (8.5) Tootsie Roll (13)
Phase VI—Evaluated after swallow		
Residual particles	Amount of particles in the mouth after swallowing	Nabisco Oatmeal Cookies (~5)
Oily mouthcoat	Amount of oily coating in the mouth after swallowing	Keebler Chips Deluxe Soft and Chewy (~5)

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[1] All flavor definitions were determined by the in-house panel (USDA-ARS, Sensory Evaluation Laboratory, Athens, GA). Basic taste definitions were obtained from Civille and Lyon (1996) and basic taste references were obtained from Meilgaard et al. (1999). All texture definitions and references were obtained from Meilgaard et al. (1999), except the references for manual hardness, manual fracturability and chewiness (in-house panel, USDA-ARS, Sensory Evaluation Laboratory, Athens, GA)

assess acceptable discriminating ability. Appropriateness of terms and their redundancy were also assessed through panel discussion.

For evaluation of each sample, attributes were presented as line-scale questions via computer software (CompusenseFive, v. 4.3, Compusense, Inc. Guelph, ON, Canada). Line-scales represented 0 to 15-point intensity scales and were anchored at 0 with ‘not perceptible’ and at 15 with ‘high intensity’. Each cookie was evaluated for all attributes. Comments were permitted at the end of the chocolate chip cookie attribute list. These comments were analyzed for trends in conjunction with line scale data.

Samples were presented in individual testing booths under low-pressure sodium-vapor lighting (CML-18, Trimble House, Norcross, GA). Samples were coded with three-digit random numbers and order of presentation was balanced (Meilgaard et al. 1999). Filtered water, apple slices and unsalted crackers were provided for palate cleansing between samples. A warm-up sample (full-fat control chocolate chip or oatmeal cookie prepared with margarine instead of butter) was provided at each session for panel self-calibration.

Panelists evaluated all formulations of both cookie types on storage days 1, 3, 5 and 7. Cookies from each formulation within a cookie type for storage days 1 and 5 or 3 and 7 were presented to panelists during a panel session. Panelists evaluated 6 cookie samples (one from each cookie formulation within cookie type for two storage days) per session; a 15-minute break was provided after the first 3 samples were evaluated.

Experimental Design and Statistical Analyses

A randomized incomplete block fractional factorial design was used. Cookie type, either CC or OAT, was blocked over the complete design. To accommodate baking, storage and sensory test schedules, it was necessary for the trained sensory panelists (n=7-8) to evaluate three treatments (FFC, RF, RFS) from the same cookie type on days 1 and 3 or days 5 and 7 of storage during a single panel session. The sensory portion of the study was replicated three times. A randomized complete block factorial design was utilized for the physicochemical and instrumental tests. This portion of the study was replicated six times. Sensory test samples and physical/physicochemical test samples from each treatment within cookie type were randomly selected from the same batches.

Results from all tests were analyzed using SAS statistical package (SAS for Windows, release 7.00, SAS, Inc., Cary, NC). Equal variance within treatment from the instrumental and sensory analyses was verified (PROC MEANS). Normality plots (PROC UNIVARIATE) were used to verify normal distribution of the data. Mixed model of analysis of variance (PROC MIXED) was used for data analysis ($p<0.05$). Least-square means (LS MEANS) and standard errors were generated. PDIFF was used for means separation (Littell et al. 1996). Relationships between sensory and instrumental data were analyzed (PROC CORR) with the Pearson's Product Moment correlation statistic ($p<0.01$).

Results and Discussion

Sensory Flavor Attributes—Overall

Overall sensory flavor profiles for the cookies by type and treatment across all storage days are found in **Figure 4.2** and **Appendix A**. The diagrams represent attribute LS-mean scores of each treatment plotted on truncated line scales radiating from a center point. Attributes are arranged in order of their evaluation beginning at the 12 o'clock

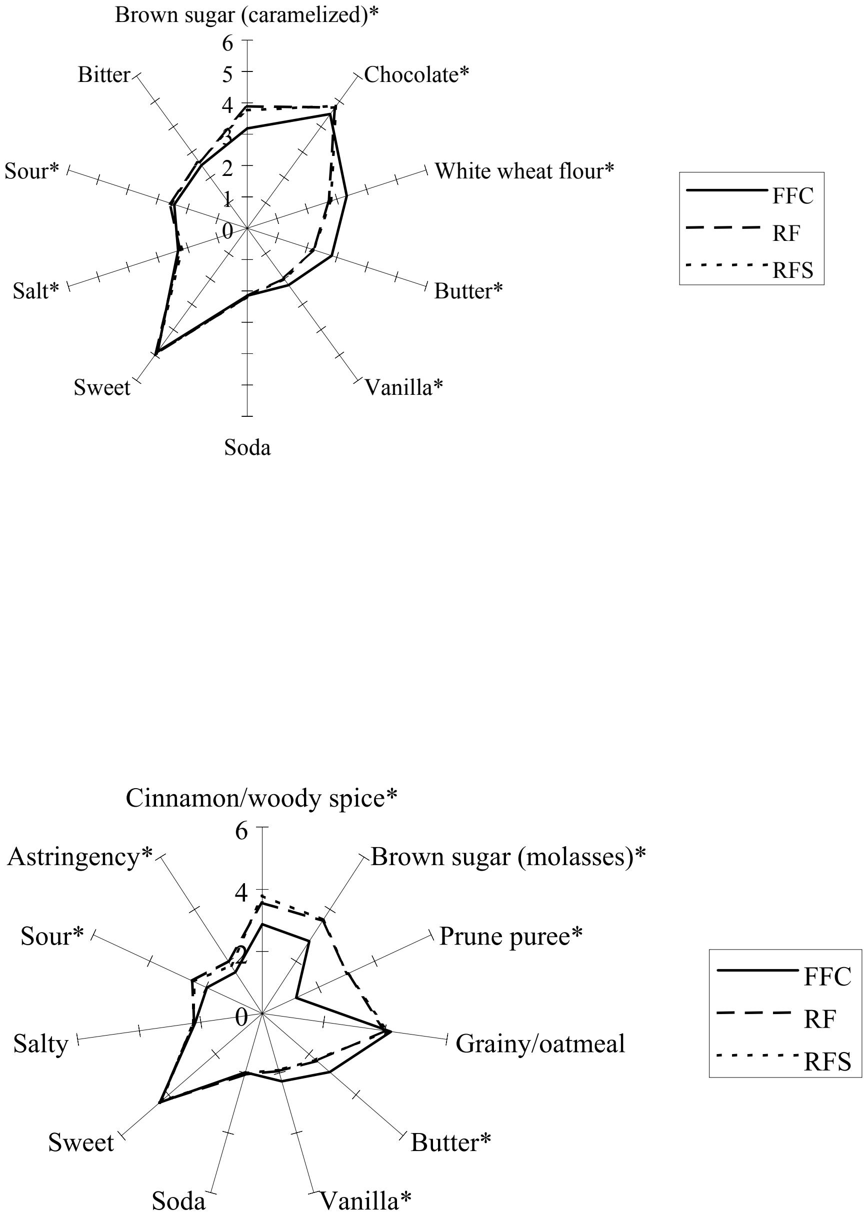


Figure 4.2. LS-Mean scores of sensory flavor attributes for chocolate chip (top) and oatmeal (bottom) cookies across 7 days of storage. Attributes are arranged in the order of evaluation beginning at the 12 o'clock position. Attributes followed by * indicates a significant difference ($p<0.05$) among formulations. L-S-Means are across 7-8 panelists and 3 replications.

position. Generally, flavor attributes of the modified cookies were more similar to each other than either was to the FFC.

Across all CC treatments, the most intense flavors were chocolate and sweet; panelists rated the cookies 4.4 to 5.0 for these attributes. Butter, vanilla, soda, salt, sour, and bitter flavors were rated lower, ranging from 1.9 to 2.8 on a 0 to 15-point line scale. Brown sugar and white-wheat flour flavor intensities were intermediate. The CC FFC had significantly more flour, butter and vanilla flavor and significantly less brown sugar (caramelized) and chocolate flavor intensity when compared to the RF and RFS. The RFS had slightly but significantly less salt flavor than the FFC; the RF was intermediate in intensity and did not differ significantly from either the FFC or RFS. The RF was perceived significantly more sour than the FFC; the RFS was intermediate and did not differ from either the FFC or RF.

Overall, sweet and grainy/oatmeal flavor were the most intense flavors in the OAT cookie type, scoring between 3.9 and 4.3 on a 0 to15-point scale. The remaining flavor attributes were less intense. The FFC was perceived to have significantly more intense butter and vanilla flavor, while the modified cookies had significantly more intense cinnamon/woody spice, brown sugar (molasses), prune puree and sour flavors and astringent afterfeel.

The increased intensity of certain flavors in the modified cookie formulas—brown sugar (molasses and caramelized), sour, chocolate, cinnamon/spice and the related afterfeel attribute astringency—suggests a possible effect of sugar and/or fat reductionand replacement. Malic acid and fructose are components of prune puree that carry and enhance other flavors in the food system. Malic acid is released more slowly than other organic acids during mastication, sustaining flavors during chewing and enhancing flavor delivery (CPB 1999a). It is possible that the flavor compounds were held and released differently in the modified cookies over the storage period, accounting for the overall differences in intensity perceived between the modified formulas and the FFC. Additionally, the fructose in the puree also contributes a perception of sweetness that may enhance other flavors in the food matrix (Alexander 1998).

The intensity of vanilla flavor in both OAT and CC FFC and of white-wheat flour in the CC FFC was greater than in the modified formulas. These flavor compounds may not have bound sufficiently to the fat replacer, or possibly were masked by the prune puree. Alternatively, in the absence of adequate lipid binding sites, the flavor compounds may have been trapped by the starch component of the cookies. Amylose forms helixes with lipophilic interiors that can bind the hydrophobic portions of flavor molecules that fit inside the helix (BeMiller and Whistler 1996). It has been reported that with carbohydrate-based fat replacers, some lipophilic flavor compounds become trapped inside the helical structure of amylose and are not released until the starch is broken down by amylase, generally after the food has been swallowed (Bennett 1992).

Increased intensity of butter flavor in OAT and CC FFC and prune puree in the OAT RF and RFS reflect product formulation (**Tables 4.1 and 4.2**). The ingredient list was not disclosed to the panelists and prune flavor was not detected in the CC cookie during lexicon development.

No significant differences were found for sweetness in either cookie type, as previously reported by Perry (2001). Redlinger and Setser (1987) reported a decrease in sweetness intensity when ace-K was used to replace 100% of the sugar in a baked shortbread cookie. Bitterness has also been attributed to ace-K in high concentrations (Stamp 1990). Retaining some sucrose in the RFS formulas may have minimized these potentially negative characteristics of ace-K. Von Rymon Lipinski and Debney (1993) noted synergistic enhancement when ace-K and sucrose, as well as ace-K and other artificial sweeteners, were combined in cola beverages. A synergistic relationship between sucrose and/or dextrose and ace-K may have compensated for the reduction in sweetness and masked any bitterness.

Sensory Flavor Interactions—Storage

According to the fixed effects model, storage effects (**Table 4.4**) were significant for sweet taste in the OAT cookie type and for salty and bitter tastes in the CC cookie type. Sweet flavor intensity in the OAT cookie type was significantly higher at day 3 than on any other storage day; days 1, 5 and 7 did not differ significantly from each other. Bitter and salt flavor intensity in the CC cookie type exhibited curvilinear behavior. Salt intensity was significantly higher on days 1 and 5 as compared to day 7. Intensity on day 3 did not differ significantly from any other storage day. Bitter flavor intensity was also significantly higher on days 1 and 5 as compared to day 7. Intensity on day 3 did not differ significantly from days 5 and 7 but was significantly lower than day 1. Although these differences are statistically significant, the practical significance in the consumer marketplace is questionable, as the sensory scores reflect minor variations across the 15-point scale.

Table 4.4. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means and standard error[1] for significant storage effects for flavor and texture attributes[2] perceived by trained panelists over a 7-day storage period

		LS-Means ± SEM			
Cookie Type	Attribute	Day 1	Day 3	Day 5	Day 7
CC	Salty	2.31b ±0.27	2.20ab ±0.27	2.31b ±0.27	2.16a ±0.27
	Bitter	2.73c ±0.30	2.47ab ±0.30	2.67bc ±0.30	2.45a ±0.30
	Manual fracturability	2.10a ±0.35	2.00a ±0.36	2.46b ±0.35	2.20ab ±0.36
	Cohesiveness	3.57b ±0.29	3.65b ±0.29	3.21a ±0.29	3.15a ±0.29
OAT	Sweet	4.14a ±0.33	4.62b ±0.33	4.29a ±0.33	4.36a ±0.33
	Cohesiveness	5.22b ±0.18	4.45a ±0.18	4.47a ±0.17	4.27a ±0.17
	Oiliness	2.78b ±0.27	2.64ab ±0.27	2.77b ±0.27	2.56a ±0.27

[1] LS-Means are across 7-8 panelists, 3 treatments per cookie type and 3 replications.

[2] Sensory scale ranged from 0 (not perceptible) to 15 (high intensity).

[abc] LS-Means within cookie type and attribute across storage days followed by the same letter are not significantly different (p<0.05) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

Sensory Flavor Attributes—Interactions

The only significant storage x treatment interaction (**Table 4.5**) was found for chocolate flavor intensity in the CC cookie type. No other significant differences in flavor attributes were found for either cookie type over the seven-day storage period. Again, the variation in sensory scores is very small on the 15-point scale (between 4.0 and 5.0) and the practical significance of this relatively minor difference over time may be minimal. Chocolate flavor intensity in both CC FFC and RF increased through storage day 5, then dropped dramatically to below the initial value. CC RFS exhibited a nearly opposite, but non-significant trend, decreasing at day 5 and then increasing to above the initial intensity at day 7. Due to these opposing trends, by day 5 the RFS had significantly more intense chocolate flavor than the RF (but did not differ from the FFC) and by day 7 the RFS was significantly higher in chocolate flavor than both the FFC and RF.

Table 4.5. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means[1] for significant treatment x storage interactions within storage day and within treatment for flavor and texture attributes[2] evaluated by trained panelists over a 7-day storage period

Cookie Type	Attribute	Treatment[3]	LS-Means ± SEM							
			Day 1		Day 3		Day 5		Day 7	
CC	Chocolate	FFC	4.54 yz	±0.20	4.58 yz	±0.21	4.71ab z	±0.20	4.14a y	±0.21
		RF	4.73 yz	±0.20	4.82 yz	±0.21	5.01b z	±0.20	4.44b y	±0.21
		RFS	4.87	±0.20	4.98	±0.21	4.49a	±0.20	4.91c	±0.21
	Manual hardness	FFC	2.86a	±0.24	2.94	±0.24	2.61a	±0.24	2.72a	±0.24
		RF	3.48b	±0.24	3.18	±0.24	3.28b	±0.24	3.20b	±0.24
		RFS	2.82a y	±0.24	3.19 yz	±0.24	3.64b z	±0.24	3.39b yz	±0.24
	Oral hardness	FFC	3.64b z	±0.21	3.44 yz	±0.21	3.06a y	±0.21	3.02a y	±0.21
		RF	3.73b	±0.21	3.67	±0.21	3.52b	±0.21	3.75b	±0.21
		RFS	3.20a	±0.21	3.36	±0.21	3.39ab	±0.21	3.61b	±0.21
OAT	Manual Fracturability	FFC	2.90b	±0.22	2.88b	±0.22	2.48b	±0.22	2.38b	±0.22
		RF	1.31a	±0.22	1.47a	±0.22	1.64a	±0.22	1.85a	±0.22
		RFS	1.32a	±0.25	1.64a	±0.26	1.73a	±0.22	1.67a	±0.22
	Oral fracturability	FFC	3.19b yz	±0.24	3.45b z	±0.24	2.51b y	±0.24	2.87b yz	±0.24
		RF	1.52a y	±0.24	1.88a yz	±0.24	2.11ab yz	±0.24	2.28a z	±0.24
		RFS	1.80a	±0.27	1.67a	±0.28	1.89a	±0.24	2.07a	±0.24
	Cohesiveness	FFC	4.72a z	±0.24	4.07a y	±0.25	5.13b z	±0.24	5.00b z	±0.25
		RF	5.77b z	±0.24	4.83b y	±0.25	4.18a xy	±0.24	3.82a x	±0.25
		RFS	5.16a z	±0.29	4.44a yz	±0.30	4.10a y	±0.24	3.97a y	±0.25
	Oral hardness	FFC	4.29 y	±0.19	4.46b yz	±0.19	4.78b yz	±0.19	4.87b z	±0.19
		RF	4.52	±0.19	4.39ab	±0.19	4.22a	±0.19	4.08a	±0.19
		RFS	4.41	±0.21	4.04a	±0.21	3.95a	±0.19	4.00a	±0.19
	Chewiness	FFC	3.73a	±0.18	3.84	0.18±	3.93	±0.18	4.15b	±0.18
		RF	3.99b	±0.18	3.87	±0.18	3.80	±0.18	3.69a	±0.18
		RFS	3.99ab	±0.19	3.92	±0.20	3.83	±0.18	3.92ab	±0.18

[1] LS-Means are across 7-8 panelists and 3 replications.

[2] Sensory scale ranged from 0 (not perceptible) to 15 (high intensity).

[3] FFC=full-fat control; RF=reduced-in-fat; 50% of the added fat was replaced with prune puree (Sunsweet Growers, Inc., Yuba City, CA); prune puree substitutions were equal to 25% of the added fat in the original formula; RFS=reduced-in-fat/sugar; in addition to fat reduction described above, 50% of the granulated sugar was replaced with Sweet One® (Stadt Corp., Brooklyn, NY) at a substitution factor of 0.06.

[abc] LS-Means for cookie type and attribute within storage day followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

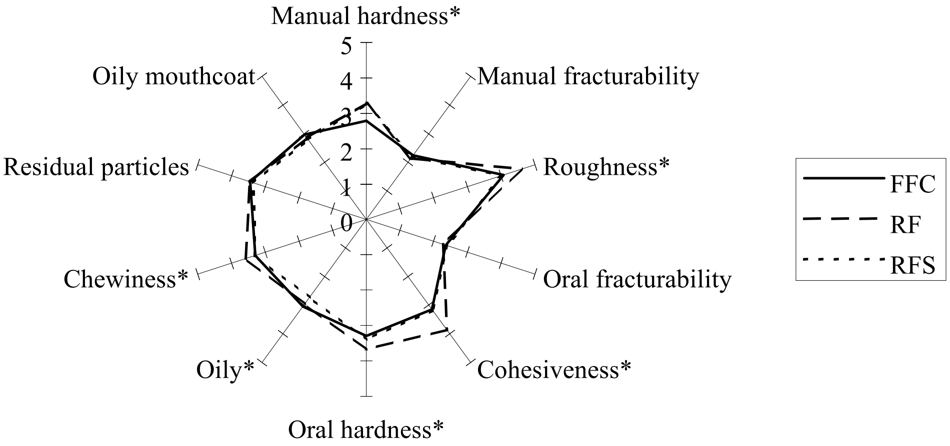
[xyz] LS-Means for treatment and attribute across the storage days followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

Within treatment, brown sugar and sweet flavor intensity generally followed the same trends as the chocolate flavor.

Panelist comments regarding the chocolate chip cookies indicate that some changes may have taken place in the cookies that were not described by the attributes or terms used in the evaluation. Several commented that storage day 5 and day 7 CC cookies (FF and RF) had a stale or rancid flavor and a strong soda aftertaste. The terms used in testing possibly did not fully capture the flavor profile of the cookies over the storage period, despite the use of 1, 3, 5 and 7-day old cookies during lexicon development. The panelists were not informed that this was a storage study.

Sensory Texture Attributes—Overall

Sensory results for texture attributes are found in **Figure 4.3** and **Appendix A**. According to the fixed effects model, panelists' assessment of chocolate chip cookie texture attributes indicated that the FFC and RFS were generally more similar to each other than either was to the RF. Judges perceived significantly greater manual hardness in both modified formulas as compared to the FFC. The RF was also judged significantly higher than FFC or RFS for surface roughness, cohesiveness, oral hardness and chewiness. Increased hardness, cohesiveness and chewiness with fat reduction may be attributed to increased moisture content of the dough and increased gluten formation. No differences in fracturability were found, indicating that although hardness increased with fat reduction, there was no significant difference in crisp texture between the cookie formulas. Perry (2001) reported similar results for reduced-in-fat chocolate chip cookies evaluated 1 day after baking.



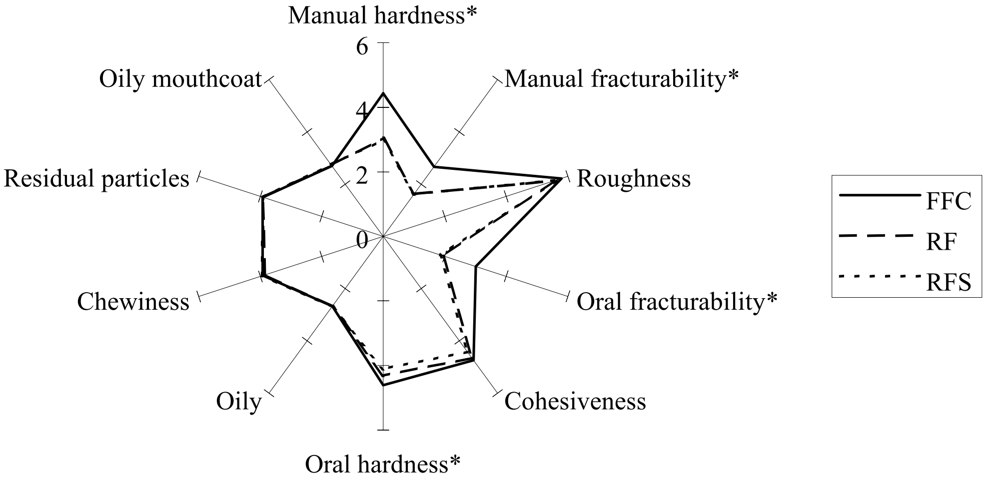


Figure 4.3. LS-Mean scores of sensory texture attributes for chocolate chip (top) and oatmeal (bottom) cookies across 7 days of storage. Attributes are arranged in the order of evaluation beginning at the 12 o'clock position. Attributes followed by * indicates a significant difference (p<0.05) among formulations. L-S-Means are across 7-8 panelists and 3 replications.

Increased surface roughness in the CC RF may simply be the consequence of position of chocolate chips within the cookie. Further, the location on the cookie surface (edge, center, etc.) used for roughness assessment was not specified and may have varied with panelists. Perry (2001) reported no differences in surface roughness for chocolate chip cookies when sugar and/or fat were replaced with alternative sweetener blend and/or prune puree. However, in that study, mini-chocolate chips rather then full-size chocolate chips were used. Similar results were reported for oatmeal cookies (Perry 2001). Significant decreases in surface roughness were found in reduced-fat chocolate chip cookies incorporating a variety of other fat replacers (Armbrister and Setser, 1994).

The modified OAT cookies were generally more similar to each other than either was to the FFC. The OAT FFC exhibited significantly increased manual and oral hardness and manual and oral fracturability as compared to the RF and RFS. Armbrister and Setser (1994) reported decreased oral firmness and decreased fracturability with the use of several fat-replacers at varying levels. Prune puree was not investigated. Swanson and Munsayac (1999) also reported that a consumer panel rated reduced-in-fat oatmeal and chocolate chip cookies made with prune puree softer than the full-fat versions. The humectant properties of the sorbitol, fructose and glucose in the prune puree help maintain the moisture level of the cookies and decrease the hardness and fracturability. Sugar replacement tended to further decrease oral hardness in OAT RFS cookies. The FFC was judged significantly harder (orally) than the RF, which was significantly harder than the RFS. The RFS was also slightly, but not significantly, less cohesive as compared to the FFC and RF cookies. The higher proportion of other ingredients to the sucrose may have interfered with the recrystallization of the remaining sucrose in the formula (Alexander 1998), producing a softer product.

Sensory Texture Attributes—Storage

Significant storage effects (**Table 4.4**) for cohesiveness for both cookie types, as well as oiliness for the OAT cookie type and manual fracturability for the CC cookie type were also identified by the panelists, according to the fixed effects model. The OAT cookie type was significantly more cohesive on day 1 as compared to the remaining storage days, whereas the CC cookie type was significantly more cohesive on days 1 and 3 as compared to days 5 and 7. Oat oiliness followed a curvilinear trend; panelists perceived significantly more oiliness on days 1 and 5 as compared to day 7. Oiliness on day 3 was not significantly different from the other storage days. CC manual fracturability was significantly higher at day 5 as compared to days 1 and 3; day 7 did not differ significantly from the other storage days. As with flavor, the practical significance of these differences over time to consumers is questionable, as the sensory scores are in a relatively narrow range of the 15-point scale.

Sensory Texture Attributes—Interactions

There were significant treatment x storage interactions (**Table 4.5**) according to the fixed effects model for sensory texture attributes of manual and oral hardness in the CC cookie type and manual and oral fracturability, oral hardness, cohesiveness and chewiness in the OAT cookie type. There were few significant changes in the individual CC formulas over the storage period. Initially, the RF was significantly manually harder than the FFC and RFS. The RFS exhibited some significant increases over time, whereas the RF and FFC did not change significantly, and by the end of the storage period, both modified cookies were significantly harder than the FFC when assessed manually. The CC formulas exhibited somewhat different trends for oral hardness. Initially, the FFC and RF were significantly harder than the RFS. The FFC softened significantly over the storage period, whereas the modified formulas did not change significantly. The RFS did, however, show a trend toward decreasing hardness. At the end of the storage period, both modified formulas were significantly harder (orally) than the FFC.

Over the storage period, OAT cookies exhibited a nearly identical trend for manual and oral fracturability. FFC cookies were significantly more fracturable, manually and orally, than the modified formulas at each of the storage days except day 5 oral fracturability, where the RF cookie was not significantly different from either of the other cookie formulas. The only significant within-treatment differences were found for oral fracturability. The FFC exhibited curvilinear behavior, while the RF tended to increase somewhat steadily across the storage period.

Initially, the FFC and RFS were less cohesive than the RF. However, both modified formulas exhibited some significant decreases in cohesiveness across the storage period, and by day 7, the FFC was significantly more cohesive than the modified cookies.

No significant differences between formulas were initially perceived for oral hardness. The FFC increased significantly across the 7-day period, whereas the modified formulas did not exhibit any significant changes. By the end of the storage period, the FFC was significantly harder than the modified formulas.

Finally, the FFC was initially significantly less chewy than the RF. The RFS was intermediate and not significantly different from the others. None of the formulas exhibited any significant within-treatment changes over the storage period, but the FFC trended toward increased chewiness and the RF trended toward decreased chewiness, so by day 7 the RF was significantly less chewy than the FFC; the RFS was still intermediate and not significantly different from the others.

For both cookie types, the sensory scores within treatment across storage, although statistically significant, are in a narrow range of the 15-point scale. The practical significance of these in the consumer marketplace is questionable.

Physical/Physicochemical Tests

Least-square means and standard errors for cookie spread are reported by cookie type and treatment in **Table 4.6**. For both cookie types, the FFC cookies were generally thin, and the RF and RFS were smaller and thicker as reported by Perry (2001), although the difference in spread between formulas was not significant in all cases. Miller et al. (1997) suggested that spread rate and set time were critical factors that determined cookie spread. Spread rate depends on dough viscosity and set time depends on the glass transition temperature of the dough.

The use of prune puree increased the moisture content of the dough and allowed more sucrose to dissolve, decreasing dough viscosity and increasing the rate of spread. However, the increased formula water (Miller et al. 1997) and fructose in the prune puree decreased set time (Doescher et al. 1987), resulting in a thicker, smaller cookie. Sugar reduction further decreased spread, as previously noted by Doescher et al. (1987), in part due to the attendant loss of bulk (Matz 1992, Nelson 2000). Also, sugar reduction and

Table 4.6. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means and standard error[1] of cookie spread analysis[2]

	CC				OAT					
	FFC[3]	RF[4]	RFS[5]	SEM	FFC[3]	SEM	RF[4]	SEM	RFS[5]	SEM
Spread	73.5c	54.2b	46.1a	±1.67	84.0b	±3.22	77.0b	±3.22	64.2a	±3.53
Adjusted Width	71.0c	63.1b	59.0a	±0.96	71.5b	±1.33	66.6a	±1.32	62.4a	±1.45
Adjusted Thickness	9.7a	11.7b	12.8c	±0.19	8.6a	±0.21	8.7a	±0.21	9.7b	±0.23

[1] LS-Means are across 6 replications.
[2] Cookie spread determined according to AACC 10-50D, 2000.
[3] FFC=full-fat control
[4] RF=reduced-in-fat; 50% of the added fat was replaced with prune puree (Sunsweet Growers, Inc., Yuba City, CA); prune puree substitutions were equal to 25% of the added fat in the original formula.
[5] RFS=reduced-in-fat/sugar; in addition to fat reduction described above, 50% of the granulated sugar was replaced with Sweet One® (Stadt Corp., Brooklyn, NY) at a substitution factor of 0.06.
[abc] LS-Means within cookie type and parameter followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

the associated percent formula weight increase in water may have increased gluten formation, decreasing dough viscosity and spread rate. The dextrose in the alternative sweetener blend may have further decreased dough viscosity (Alexander 1998) and limited spread. Adjusted thickness results are generally consistent with the probe data for product height, although the heights collected in probing may be more accurate as they are an average of the height at each of the 9 probe points across the cookie surface.

Least-square means and standard errors for water activity are reported by cookie type and treatment in **Table 4.7**. According to the fixed effects model, storage effects were significant for both cookie types. The OAT cookie type exhibited significant increases in water activity at days 3 and 5; day 7 was not significantly different from day 5. The CC cookie type increased steadily and significantly at each successive storage day.

Table 4.7. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means and standard error[1] of water activity[2]; storage effects, treatment effects and interaction effects

		CC				OAT			
		LS-Means ± SEM				LS-Means ± SEM			
Storage	Day 1	0.53a±0.01				0.50a±0.01			
	Day 3	0.55b±0.01				0.51b±0.01			
	Day 5	0.57c±0.01				0.52c±0.01			
	Day 7	0.59d±0.01				0.53c±0.01			
		FFC	RF	RFS	SEM	FFC	RF	RFS	SEM
Treatment[3]		0.53e	0.56f	0.59g	±0.01	0.41f	0.57g	0.57g	±0.01
Treatment x Storage	Day 1	0.50h	0.52h	0.57h	±0.01	0.39	0.54	0.56	±0.01
	Day 3	0.52i	0.54h	0.59hi	±0.01	0.41	0.56	0.57	±0.01
	Day 5	0.54j	0.57i	0.60i	±0.01	0.41	0.58	0.58	±0.01
	Day 7	0.58k	0.59j	0.60i	±0.01	0.42	0.59	0.59	±0.01

[1] LS-Means are across 6 replications with 4 analysis per storage day per replications.

[2] Water activity measured using Aqua Lab (Decagon Devices, Pulman, WA). Aliquots were taken from composite samples as described by Curley and Hoseney (1984).

[3] FFC=full-fat control; RF=reduced-in-fat; 50% of the added fat was replaced with prune puree (Sunsweet Growers, Inc., Yuba City, CA); prune puree substitutions were equal to 25% of the added fat in the original formula; RFS=reduced-in-fat/sugar; in addition to fat reduction described above, 50% of the granulated sugar was replaced with Sweet One® (Stadt Corp., Brooklyn, NY) at a substitution factor of 0.06.

[abcd] LS-Means within cookie type followed by the same letter are not significantly different ($p<0.05$) across storage days according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

[efg] LS-Means within cookie type and treatment followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

[hijk] LS-Means within cookie type and treatment across storage days followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

Overall treatment water activity values increased with modification, similar to findings reported by Perry (2001). This overall increase in water activity due to fat reduction may be attributed to the prune puree. Although the puree is 15% sorbitol (CPB 1999a), the humectant properties of the sorbitol may not have adequately compensated for the overall increase in formula water. Nutritive sweeteners bind water (Alexander

1998), and replacement of a portion of the sucrose with the alternative sweetener blend may have further increased water activity values.

Only the CC cookie type exhibited a significant treatment x storage interaction, with all CC formulations having some significant increases over the 7-day period. The overall and storage period water activity values for both cookie types do not indicate increased susceptibility to microbial growth. Non-microbial spoilage may be an issue at these water activity levels, as the rate of lipid oxidation increases between water activity values of 0.4 to 0.7 (Given 1993). Unpleasant off-flavors and odors are produced as the triglycerides break down and may impact sensory flavor attributes. However, sensory results do not reflect any spoilage effects, although off-flavors and odors were not specifically identified for evaluation in this study. The panelists' comments about the 5 and 7-day old CC cookies suggest some oxidation effects, and further study is needed to determine if additional evaluation terms would better capture these cookie characteristics over the storage period.

Changes in water activity over the storage period may have been due to water movement. As sucrose recrystallizes, it releases water, which can then migrate to other components (Hoseney 1986) or simply evaporate.

Probing Parameters—Treatment

LS-Means and standard error of probing parameters for treatment effects are presented in **Table 4.8**. Cookie type influenced effect of modification. Sanchez et al. (1995) proposed that cookie toughness was indicated by area under the curve. Based on this interpretation, the CC FFC was less tough than the RF, which was less tough than the RFS based on area to first peak (A1). The area to maximum peak (AMP) values indicate

Table 4.8. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means and standard error[1] of probing parameters[2] for treatment effects

Probe	CC—LS-Means ± SEM			OAT—LS-Means ± SEM		
Parameters	FFC[3]	RF[4]	RFS[5]	FFC[3]	RF[4]	RFS[5]
A1	104.96a ±14.47	200.81b ±14.48	235.81c ±14.47	265.01b ±20.06	148.06a ±20.16	132.52a ±20.56
F1 (g)	554.89 ±41.17	691.47 ±41.21	710.27 ±41.18	1410.71c ±85.53	750.79b ±86.04	585.49a ±88.16
S1 (g/s)	2330.87b ±236.32	1978.67b ±236.42	1616.59a±236.35	4579.44c±366.86	2735.71b±368.53	1943.09a±375.51
AMP	170.81a ±49.54	394.73b ±49.55	411.60b ±49.54	361.38b ±47.62	237.16a ±47.70	257.40a ±48.00
FMP (g)	604.54a ±63.34	861.03b ±63.36	847.91b ±63.34	1498.56c ±96.46	779.21b ±96.94	616.86a ±98.93
AS (g/s)	690.33 ±39.92	768.48 ±40.40	668.86 ±40.16	1643.71c±111.12	646.66b±112.53	420.62a±115.85
Height (mm)	8.17a ±0.56	9.91b ±0.56	11.00c ±0.56	7.69a ±0.21	8.95b ±0.21	9.90c ±0.21

[1] LS-Means are across 6 replications with 9 probes per cookie and 4-5 cookies per replication; measured using a 50-kg capacity TA.XT2 Texture Analyzer (equipped with Texture Expert Exceed, Version 2.13, Stable Micro Systems, Haselmere, Surrey, England) and 0.3-cm probe at a crossarm speed of 5mm/sec, as described by Bourne (1975, 1999) and Gaines et al. (1992).

[2] A1=area to first peak; F1=force to first peak; S1=slope to first peak; AMP=area to maximum peak; FMP=force to maximum peak; AS=average slope

[3] FC=full-fat control

[4] RF=reduced-in-fat; 50% of the added fat was replaced with prune puree (Sunsweet Growers, Inc., Yuba City, CA); prune puree substitutions were equal to 25% of the added fat in the original formula.

[5] RFS=reduced-in-fat/sugar; in addition to fat reduction described above, 50% of the granulated sugar was replaced with Sweet One® (Stadt Corp., Brooklyn, NY) at a substitution factor of 0.06.

[abc] LS-Means within cookie type and probe parameter across treatments followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

that the CC FFC was less tough than the modified cookies, which didn't differ significantly from one another. Sensory evaluation results were in conflict with this finding. Although the panelists did not evaluate toughness as defined by Jowitt (1974)—"…a high and persistent resistance to breakdown on mastication"—they did evaluate the related attribute chewiness, defined by the panelists as the amount of work to chew the sample to the point of swallow. Panelist' scores indicated that the CC FFC and RFS were significantly less chewy than the RF.

For the OAT cookie type, both A1 and AMP values were significantly larger for the FFC than the modified formulas, indicating increased toughness in the FFC. No sensory differences were found among the OAT formulas for chewiness.

Gaines (1994) and Gaines et al. (1992) interpreted force as an indication of hardness. For the CC cookie type there were no significant differences between force at first peak (F1). However, force at maximum peak (FMP) indicated that the CC FFC was significantly less hard than the modified formulas, in agreement with panelists' assessment of manual hardness. Sensory results for oral hardness did not follow this same trend. Differences between instrumental and sensory results can possibly be explained by changes that the product undergoes as it is wetted with saliva and warmed in the mouth (Gaines 1994).

The OAT FFC exhibited significantly higher force values than the RF, which was significantly higher than the OAT RFS, indicating significant decreases in cookie hardness with fat replacement and fat and sugar replacement, respectively. Panelists' evaluation of oral hardness is in agreement with this interpretation, whereas manual hardness scores indicate that the OAT FFC was harder than both modified formulas, which did not differ significantly from one another.

Finally, slope to first peak (S1) values indicate that the CC FFC and CC RF were significantly more brittle than the CC RFS; average slope (AS) values indicate no significant differences among cookie formulas. In the three-point break test, slope is used to indicate brittleness, as it demonstrates the amount of deformation before the product breaks. Similarly, the slope obtained during probing indicates the extent to which the product will deform prior to the probe penetrating the cookie surface, and is a good indicator of brittleness. Panelists found no significant differences between formulas for manual or oral fracturability.

S1 and AS values indicate that the OAT FFC was significantly more brittle than the OAT RF, which was significantly more brittle than the OAT RFS. Panelists' assessment indicated that the OAT FFC was significantly more fracturable than the modified formulas, which did not differ significantly from one another.

Probing Parameters—Storage

According to the fixed effects model, there were significant changes over the storage period in brittleness and toughness for both OAT and CC cookie types, and in hardness for the OAT cookie type (**Table 4.9**). Both cookie types exhibited increased brittleness over time, based on both S1 and AS parameters. Brittleness of CC cookies increased significantly between days 1 and 3 and again between days 5 and 7. Brittleness of OAT cookies increased significantly between days 1 and 3 and again between days 3 and 5, and leveled off after day 5. Increased brittleness may be due to the recrystallization of sucrose, which increases the water available to complex with other

Table 4.9. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means and standard error[1] of probe parameters[2] for storage effects

Cookie Type	Probe Parameter	LS-Means ± SEM			
		Day 1	Day 3	Day 5	Day 7
CC	A1	247.73d ±15.34	204.79c ±15.36	148.53b ±15.34	121.04a ±15.34
	F1 (g)	663.79 ±43.95	677.24 ±44.02	602.63 ±43.95	665.17 ±43.96
	S1 (g/s)	1317.07a ±250.38	1740.61b ±250.55	2043.96b ±250.38	2799.88c ±250.43
	AMP	315.05 ±50.41	332.86 ±50.42	317.82 ±50.41	337.12 ±50.41
	FMP (g)	707.40 ±65.70	764.47 ±65.75	754.92 ±65.70	857.86 ±65.71
	AS (g/s)	555.39a ±48.42	662.04b ±44.92	735.10b ±43.36	884.36c ±42.12
OAT	A1	215.47b ±21.16	176.23a ±21.41	176.83a ±21.21	158.92a ±21.11
	F1 (g)	780.25a ±90.82	883.12a ±91.95	1015.59b ±90.91	983.69b ±90.74
	S1 (g/s)	2176.75a ±384.92	2818.49b ±388.80	3591.64c ±385.30	3757.43c ±384.54
	AMP	311.19b ±48.32	286.62ab ±48.54	283.13a ±48.37	260.31a ±48.27
	FMP (g)	814.86a ±101.82	945.23b ±102.86	1068.04c ±101.88	1031.38c ±101.75
	AS (g/s)	795.34a ±123.74	881.01b ±124.42	990.44bc ±122.35	947.87c ±121.63

[1] LS-Means are across 6 replications with 9 probes per cookie and 4-5 cookies per replication; measured using a 50-kg capacity TA.XT2 Texture Analyzer (equipped with Texture Expert Exceed, Version 2.13, Stable Micro Systems, Haselmere, Surrey, England) and 0.3-cm probe at a crossarm speed of 5mm/sec, as described by Bourne (1975, 1999) and Gaines et al. (1992).

[2] A1=area to first peak; F1=force to first peak; S1=slope to first peak; AMP=area to maximum peak; FMP=force to maximum peak; AS=average slope

[abcd] LS-Means within cookie type and probe parameter across storage days followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

components of the cookie. Curley and Hoseney (1984) previously reported that sucrose-containing cookies increased in brittleness, i.e., developed a characteristic ‘snap’ between 1 and 3 days and did not exhibit further changes up to 5 days. Snap development was accompanied by increased water activity in the Curley and Hoseney study. Water activity data reported in Table 7 also appears to support this hypothesis.

Both F1 and FMP values indicated a significant increase in hardness over time in the OAT cookies; all significant changes occurred by day 5. A1 and AMP indicated a decrease in toughness in OAT cookies at the beginning of the storage period, which then leveled off. For the CC cookie type, A1 indicated a significant decrease in toughness at each storage day; AMP values did not follow this trend.

Probing Parameters—Interactions

Generally, fixed effects model results indicated few significant treatment x storage interactions (**Table 4.10**). The OAT FFC was initially harder and more brittle than the modified cookies. The OAT FFC did not exhibit any significant changes over time, whereas the modified cookies exhibited increased hardness, brittleness and decreased toughness over the storage period. The OAT RF tended to change to a greater extent than the OAT RFS.

The CC FFC was initially significantly less tough than the modified cookies, which did not differ from one another. Over the storage period, all formulas exhibited some significant decreases in toughness, and by day 7 the CC RF and CC FFC were significantly less tough than the CC RFS. For all other parameters, the CC cookies did not exhibit any significant interactions over the storage period.

Correlations Between Probing and Trained Sensory Panel Results

Correlation analysis (**Table 4.11**) was conducted to determine if sensory and instrumental measurements of texture were linearly related. Cookie type influenced correlation results. Generally, a lower degree of relationship was found with correlations between oral determinations of textural attributes and probe results as compared to manual determination of attributes and probe results. This is likely due to the changes undergone in the mouth as a product is warmed and interacts with saliva during mastication.

Table 4.10. Chocolate chip (CC) and oatmeal (OAT) cookies: LS-Means and standard error[1] of probe parameters[2] for treatment x storage interactions

		CC—LS-Means ± SEM						OAT—LS-Means ± SEM					
	Day	FFC[3]		RF[4]		RFS[5]		FFC[3]		RF[4]		FS[5]	
A1	1	141.69c y	±21.03	326.89d z	±21.03	274.63b z	±21.03	239.05	±27.38	208.56b	±27.39	198.81b	±28.53
	3	125.21c x	±21.03	213.03c y	±21.19	276.12b z	±21.03	283.66 z	±27.49	124.60a y	±28.66	120.44a y	±28.66
	5	82.44b x	±21.03	157.11b y	±21.03	206.04a z	±21.03	282.98 z	±27.53	136.80a y	±27.49	110.70a y	±28.61
	7	70.48a y	±21.03	106.20a y	±21.03	186.45a z	±21.05	254.35 z	±27.27	122.28a y	±27.25	100.11a y	±28.45
F1 (g)	1	577.11	±61.84	762.39	±61.84	651.87	±61.84	1302.94	±119.69	538.19	±119.71	499.64	±125.49
	3	568.43	±61.84	711.81	±62.26	751.47	±61.84	1492.82	±119.88	633.24	±125.72	523.31	±125.72
	5	496.03	±61.84	645.78	±61.84	666.09	±61.84	1530.64	±119.95	868.40	±119.88	647.73	±125.62
	7	577.97	±61.84	645.91	±61.84	771.63	±61.92	1316.44	±119.50	963.33	±119.46	671.30	±125.35
S1 (g/s)	1	1701.92	±342.66	1179.08	±342.66	1070.21	±342.66	4519.77 z	±487.13	1038.37a y	±487.22	972.12a y	±507.35
	3	2018.89	±342.66	1763.19	±343.74	1439.74	±342.66	4817.88 z	±488.20	2064.51b y	±508.40	1573.09b y	±508.40
	5	2358.15	±342.66	2157.37	±342.66	1616.35	±342.66	4865.69 z	±488.33	3514.95c z	±487.99	2394.27c y	±507.94
	7	3244.53	±342.66	2815.04	±342.66	2340.07	±342.97	4114.42 yz	±486.27	4325.00c z	±486.07	2832.86c y	±506.71
AMP	1	183.93	±56.90	387.79	±56.90	373.44	±56.90	340.20	±52.57	291.69	±52.57	301.68	±53.68
	3	187.66	±56.90	399.81	±57.01	411.11	±56.90	385.06	±52.69	227.02	±53.84	247.79	±53.84
	5	158.91	±56.90	386.78	±56.90	407.77	±56.90	369.20	±52.74	233.80	±52.69	246.38	±53.77
	7	152.74	±56.90	404.53	±56.90	454.10	±56.93	351.05	±52.43	196.15	±52.40	233.74	±53.58
FMP (g)	1	602.44	±82.22	797.79	±82.22	721.96	±82.22	1366.17 z	±131.82	559.38a y	±131.84	519.03a y	±137.39
	3	614.50	±82.22	838.26	±82.55	840.65	±82.22	1619.08 z	±131.96	657.77a y	±137.56	558.85ab y	±137.56
	5	556.77	±82.22	875.26	±82.22	832.73	±82.22	1616.79 z	±132.02	910.11b y	±131.96	677.20b x	±137.49
	7	644.45	±82.22	932.81	±82.22	996.32	±82.29	1392.19 z	±131.68	989.58b y	±131.65	712.36b x	±137.29
AS (g/s)	1	572.08	±77.02	544.89	±82.78	549.20	±75.07	1669.58 z	±180.26	414.35a y	±186.23	302.09a y	±192.42
	3	703.01	±71.72	644.36	±71.29	638.74	±73.09	1753.59 z	±181.21	512.30a y	±190.57	377.14ab y	±189.98
	5	659.38	±69.05	851.90	±67.38	694.02	±70.54	1760.36 z	±181.39	750.60b y	±180.43	460.36bc x	±189.08
	7	826.84	±66.62	1032.76	±66.15	793.48	±67.32	1391.32 z	±179.83	909.39b y	±178.83	542.91c x	±187.90

[1] LS-Means are across 6 replications with 9 probes per cookie and 4-5 cookies per replication; measured using a 50-kg capacity TA.XT2 Texture Analyzer (equipped with Texture Expert Exceed, Version 2.13, Stable Micro Systems, Haselmere, Surrey, England) and 0.3-cm probe at a crossarm speed of 5mm/sec, as described by Bourne (1975, 1999) and Gaines et al. (1992).

[2] A1=area to first peak; F1=force to first peak; S1=slope to first peak; AMP=area to maximum peak; FMP=force to maximum peak; AS=average slope

[3] FFC-full-fat control

[4] RF=reduced-in-fat; 50% of the added fat was replaced with prune puree (Sunsweet Growers, Inc., Yuba City, CA); prune puree substitutions were equal to 25% of the added fat in the original formula.

[5] RFS=reduced-in-fat/sugar; in addition to fat reduction described above, 50% of the granulated sugar was replaced with Sweet One® (Stadt Corp., Brooklyn, NY) at a substitution factor of 0.06.

[abcd] LS-Means within cookie type, treatment and parameter across storage days followed by the same letter are not significantly different ($p<0.05$) according to mixed ANOVA and LS-Means separation with PDIFF.

[xyz] LS-Means within cookie type, parameter and storage days across treatments followed by the same letter are not significantly different (<0.05) according to mixed ANOVA and LS-Means separation with PDIFF (Littell et al. 1996).

Table 4.11. Pearson's correlation coefficients[1] between sensory attributes[2] and probe results[3] for chocolate chip (CC) and oatmeal (OAT) cookies

Sensory Attributes		CC Probe Parameters[4]						OAT Probe Parameters[4]					
		A1	S1	F1	AS	FMP	AMP	A1	S1	F1	AS	FMP	AMP
Manual Hardness	r	0.350	-0.037	0.567	0.189	0.628	0.616	0.765	0.533	0.729	0.711	0.714	0.758
	p	0.036	0.829	0.000	0.268	<0.0001	<0.0001	<0.0001	0.001	<0.0001	<0.0001	<0.0001	<0.0001
Manual Fracturability	r	-0.296	0.176	-0.284	0.135	-0.145	-0.178	0.567	0.660	0.745	0.798	0.762	0.602
	p	0.078	0.304	0.093	0.429	0.396	0.297	0.000	<0.0001	<0.0001	<0.0001	<0.0001	0.000
Roughness	r	0.120	0.092	0.280	0.204	0.323	0.278	0.330	0.142	0.258	0.255	0.241	0.419
	p	0.484	0.591	0.098	0.231	0.054	0.100	0.056	0.421	0.140	0.145	0.169	0.013
Oral Fracturability	r	-0.207	0.285	-0.018	0.355	0.156	0.006	0.517	0.730	0.765	0.806	0.788	0.579
	p	0.224	0.091	0.913	0.033	0.363	0.969	0.001	<0.0001	<0.0001	<0.0001	<0.0001	0.000
Cohesiveness	r	0.407	-0.236	0.455	-0.079	0.345	0.385	0.392	-0.318	-0.063	-0.075	-0.083	0.276
	p	0.013	0.165	0.005	0.646	0.039	0.020	0.021	0.066	0.721	0.670	0.638	0.113
Oral Hardness	r	0.339	-0.160	0.488	0.072	0.485	0.462	0.645	0.123	0.393	0.295	0.356	0.596
	p	0.042	0.350	0.002	0.676	0.002	0.004	<0.0001	0.485	0.021	0.089	0.038	0.000
Oiliness	r	-0.050	0.018	0.036	0.123	-0.064	-0.161	0.090	-0.164	-0.088	-0.149	-0.116	0.018
	p	0.769	0.914	0.832	0.471	0.709	0.346	0.610	0.351	0.617	0.398	0.512	0.915
Chewiness	r	0.323	-0.029	0.513	0.210	0.452	0.397	0.240	-0.242	-0.048	-0.107	-0.076	0.215
	p	0.054	0.866	0.001	0.217	0.005	0.016	0.171	0.167	0.785	0.546	0.667	0.220
Residual Particles	r	-0.193	0.269	0.042	0.430	0.160	0.028	-0.040	-0.102	-0.095	-0.060	-0.083	-0.072
	p	0.257	0.112	0.807	0.008	0.349	0.867	0.818	0.564	0.590	0.734	0.638	0.683
Oily Mouthcoat	r	0.133	-0.082	0.164	0.022	-0.002	-0.039	0.033	-0.255	-0.179	-0.194	-0.189	-0.048
	p	0.437	0.633	0.336	0.895	0.990	0.818	0.849	0.144	0.310	0.270	0.284	0.785

[1] r=correlation coefficient; p=significance level; bold values indicate significance ($p<0.01$).
[2] Correlation values are across 7-8 panelists by 4 storage days by 3 replications within cookie type. Sensory scale ranged from 0=low intensity to 15=high intensity.
[3] n=324; measured using a 50-kg capacity TA.XT2 Analyzer (equipped with Texture Expert, Version 1.20, Stable Micro Systems, Haselmere, Surrey, England) and a 0.3-cm probe at a crossarm speed of 5mm/sec as described by Bourne (1975, 1982) and Gaines et al. (1992).
[4] A1=area to first peak; F1=force to first peak; S1=slope to first peak; AMP=area to maximum peak; FMP=force to maximum peak; AS=average slope

The OAT cookie type showed highly significant correlations between sensory evaluation of manual hardness, manual fracturability and oral fracturability and all probe parameters reported. A1 and AMP were the best indicators of hardness, predicting 58% and 57 % of the variation in manual hardness and 42% and 36% of the variation in oral hardness, respectively. These results suggest that area may be a better indicator of hardness than the traditional indicator, force. However, force parameters were also adequate indicators of manual and oral fracturability, predicting between 56% and 62% of the variation. AS was the best single indicator of manual and oral fracturability, explaining 64% and 65% of the variation, respectively.

Fewer significant correlations were found between sensory and instrumental results for the CC cookie type. Although correlations were highly significant, r values indicated relatively low percentage explanation of the differences found, ranging from 11% to 39%. F1, FMP and AMP parameters correlated significantly with manual and oral hardness. Chocolate chips in the cookie matrix may have influenced both instrumental and sensory evaluation results. The chips were not avoided during probing, and it is unknown how the panelists assessed the chips in relation to the cookie matrix.

Previously, Perry (2001) reported that area under the curve (area to maximum peak used here) was the best indicator of cookie texture for both cookie types and correlated significantly with hardness, chewiness and cohesiveness. Storage period, differences in flour, baking time, cookie weight and size of the chocolate chips used may explain the different results found in this study.

Conclusions

Trained sensory descriptive panelists found differences between the FFC and modified formulas, both in flavor and texture. However, it appears that sugar and/or fat reduction minimally affected the sensory characteristics of both cookie types over the seven-day storage period. Differences between the full-fat control and the reduced-in-sugar and/or fat formulas and changes in flavor and texture over storage do not necessarily indicate that the products would be unacceptable to consumers. Perry (2001) found that reduced-fat and reduced-fat and sugar oatmeal cookies more closely resembled the "ideal" identified by a consumer panel in flavor and texture than did the full-fat control. Likewise, texture of reduced-fat and reduced-fat and sugar chocolate chip cookies was closer to the consumer ideal than the full-fat control. Cookies were evaluated one day after baking in that study. Consumer acceptability over a reasonable storage period should also be explored.

Probe results indicated very few changes in any chocolate chip cookie formula over the storage period. The modified oatmeal formulas tended to exhibit more significant changes over time, generally becoming more similar to the full-fat control as they aged. Few significant correlations were found between sensory and instrumental results for the CC cookie type. Area to maximum peak and force parameters and correlated significantly with manual and oral hardness. More significant correlations were found for the OAT cookie type. Manual hardness, manual fracturability and oral fracturability correlated with all probe parameters reported.

Correlations suggest there is a relationship between instrumental assessment of area and sensory assessment of hardness and between instrumental assessment of slope and sensory assessment of fracturability in a relatively homogenous product like oatmeal cookies. However, lower correlations for the chocolate chip cookie type suggest that the point assessment of the probe does not reflect the integration of the cookie matrix and novelty inclusions like chocolate chips by the sensory panelists.

Because texture has multiple attributes, regression analysis may further improve correlation with sensory data, as it allows several instrumental parameters to be used simultaneously to predict sensory response (Szczesniak 1987). Thus the need for potentially costly and time-consuming texture evaluation with a trained sensory panel during product development and optimization may be reduced.

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CHAPTER V

COMPARISON OF TWO SENSORY COLOR EVALUATION METHODS WITH TWO INSTRUMENTAL TECHNIQUES

Abstract

Color influences appearance and provides clues to product flavor and texture; all affect consumer acceptability. Color spectrophotometers are frequently used to assess food color. Digital images analyzed with graphics software are a potential alternative. Instrumental color measurement techniques must be accurate, convenient, quantitative and reflective of human sensory perception.

Our objectives were: (1) to assess two instrumental and two visual sensory techniques for color measurement of 3 formulations of 2 cookie types; and (2) to determine if instrumental techniques reflected sensory assessments.

Cookie color, manipulated with a non-sucrose sweetener blend and/or prune puree, was evaluated under cool white fluorescent illumination. CIELAB and hue angle were determined on three cookies per formulation type (chocolate chip and oatmeal) with a Minolta color spectrophotometer. CIELAB values were also obtained from high-resolution digital camera cookie images with Adobe Photoshop. Eight-10 sensory panelists compared cookies to equidistant physical color reference cards on a 10-point intensity scale (1=light to 10=dark), in a Macbeth light booth. Sensory panelists also compared cookies to equidistant digital color references on a 10-point intensity scale presented via computer (Compusense) in sensory booths. Two replications were obtained, 3 days post-bake. ANOVA and PDIFF verified differences ($p<0.05$) among cookies within type. T-tests identified differences between instrumental or sensory methods ($p<0.05$). Correlations identified relationships between assessment methods ($p<0.01$).

All methods reflected differences in product formulations. Despite significant T-test values between most instrumental CIELAB values, a strong linear relationship ($r=0.99$, $p<0.0001$; hue angle) existed between the methods. Both sensory methods were similarly effective ($r=0.97$-0.98, $p<0.001$) in identifying differences for both cookie types. Instrumental and sensory correlations for both cookie types ($r=0.97$, $p<0.0001$; hue angle) validated the potential of both instrumental methods.

All evaluation methods tested were successful. Method selection depends on specific application and desired endpoint. Digital method advantages include a permanent image useable in several evaluative ways.

Introduction

Acceptability or desirability of a food hinges on flavor, texture and appearance, including color, as well as safety and nutritive value. Consumers are unlikely to purchase or consume products that are visually unappealing (Setser 1984). Further, appearance of a food product determines whether a product will be eaten the first time and is often used as an indication of flavor (Lawless 1985). Foods may be rejected because product color warns the consumer of off-flavors or spoilage.

Color can provide important cues for flavor identification in foods that lack distinguishing textural cues, such as sherbets and soft drinks. It has also been shown to affect taste thresholds for sweet, sour and bitter and to affect the perception of sweetness. These relationships between color and food safety, acceptability and preference are generally learned associations (Clydesdale 1993).

Baked products such as cookies are generally eaten for enjoyment rather than for their nutritive value, and it can be argued that appearance plays a crucial role in cookie selection. Traditionally, the baking industry has relied on sensory judgments made on the production line for informal quality control (Hutchings 1999). These informal evaluations have been used to verify consistency between product lots, assess the effect of ingredient substitutions and to compare products with competitors'. This may be a suitable method for certain applications, since discrimination of minute color differences is less important in products for which there is a wide range of acceptable colors (Hutchings 1999). However, accurate color quantification is often desirable, especially during product development or modification.

Human color vision is fairly consistent (barring any deficiencies or abnormalities), and small sensory panels can be used for sensory color evaluation (Setser 1984). However, using a sensory panel for color analysis can be a costly, complicated, and lengthy process. Panelists must have accurate color vision and be available for panel sessions. For accurate and reproducible color evaluation, controlled sample presentation and controlled lighting conditions are crucial. Light booths such as the Macbeth SpectraLight II (Kollmorgen Instrument Corp., New Windsor, NY) provide a means for controlling lighting conditions. The booths offer several illuminant options and do not require calibration. However, the Macbeth booths may be cost prohibitive and permit evaluation by only one panelist at a time, unless several booths are available.

Sensory evaluation methods may also require the creation and use of reference colors. Selection and maintenance of existing physical color references or creation and standardization of custom physical or digital color references may be a cumbersome task. Further, confusion may arise when panelists attempt to describe, match or communicate a color that falls between the limited color reference samples available (Francis 1983).

Although they cannot replace human visual assessment, instrumental methods that provide rapid, inexpensive color measurement are desirable and have many industry applications, including research, quality control, product tolerances (Francis 1983) and monitoring process steps (Mabon 1993). It is fundamental that instrumental color measurement techniques are accurate, convenient, precise and quantitative (Marsili 1996), and are reflective of human sensory perception of color (Setser 1984).

Color spectrophotometers are commonly used for food color measurement (Mabon 1993). The spectrophotometer generates a spectral curve representing the reflectance or transmittance of light from the surface being measured as compared to that reflected by a reference standard. The instrument uses the values from the reflectance measurements to calculate tristimulus values, which can then be converted to various color space values. The L*a*b* color model (CIELAB), introduced in 1976 by the Commission International de l'Eclariage (CIE) is an opponent model that describes color in terms of lightness (L*) ranging from 0 to 100, redness or greenness (+/-a*) and yellowness or blueness (+/-b*). Hue angle (arctan[b*/a*]) is a calculated value that describes color in degrees, starting on the a* axis with +a* (red) at 0° and proceeding counterclockwise around the color space with +b* (yellow) at 90°, -a* (green) at 180° and –b* (blue) at 270° (Billmeyer and Saltzman 1981).

Swanson and others (1999) used a color spectrophotometer to evaluate the difference in color resulting from fat reduction in peanut butter cookies. Fat was replaced at either 75% or 100% levels with a carbohydrate-based fat replacer. Varying levels of two emulsifiers were used in combination with the fat-replacer. L, a and b values and hue angle were reported. Only the L value was affected by fat replacement; the modified cookies were significantly lighter than the control.

A color measurement method for food products using a high-resolution digital camera, personal computer (PC) and graphics software to determine CIELAB values has been proposed by Papadakis and others (2000). Images from the digital camera are downloaded onto the PC and opened in Adobe Photoshop (Adobe Systems, Inc., San Jose, CA), a software program that is capable of displaying and reporting color values according to the CIELAB color model. This method allows color measurement across a user-defined area of the food surface, in contrast to the 'point' measurement obtained by color measurement tools like the color spectrophotometer. Additionally, the color image can be preserved for future reference. Papadakis and others (2000) used this system successfully to measure the color of cereal bars and microwave pizza crusts.

Little literature is available addressing the possible correlation between sensory color evaluation techniques and instrumental color measurement methods. Ultimately, because food is judged with the human eye, it is essential that any instrumental measurement technique reflect sensory evaluation. The proposed digital camera method may be a flexible, relatively inexpensive color measurement option. Further information about the correlation between this method and more traditional instrumental methods and sensory methods is needed.

Our objectives were: (1) to assess two visual sensory color evaluation methods—using physical references in a Macbeth light booth and using digital references in a sensory booth—and two instrumental color measurement techniques—the color spectrophotometer and digital camera/software method—for color measurement of three formulations of two cookie types; and (2) to determine if instrumental techniques reflected sensory color assessments.

Materials and Methods

A randomized complete block factorial design was utilized. Sensory panelists (n=8-10) evaluated three treatments (full-fat control (FFC), reduced-in-fat (RF) and reduced-in-fat-and-sugar (RFS)) of chocolate chip (CC) or oatmeal (OAT) cookie type during a single session. The treatment combinations used for the sensory panel was also used for instrumental color analysis. Two replications were obtained, 3 days post-bake.

Cookie formulations were developed by Swanson and Munsayac (1999) and Perry (2001). For both cookie types, the RF and RFS versions incorporated prune puree as a fat replacer at the levels recommended by the California Dried Plum Board (1999). Half of the initial amount of added fat was removed from the formulation and 25% of the initial amount of fat was replaced with prune puree. Sugar replacement with an acesulfame-K/dextrose blend (Sweet One®) was also made according to manufacturer's recommendations (Sweet One® 1998). For both types of RFS cookies, half of the granulated sugar in the control formulation was removed and replaced based on the following equivalency: 16.6 grams granulated sugar was replaced by 1 gram of Sweet One®.

Ingredients were from the same lot whenever possible. If multiple lots of a single ingredient were used, all lots were combined and aliquots drawn as needed. Eggs and butter, which were purchased weekly, were from the same lot within each purchase. Dry ingredients and butter were weighed one day in advance. Eggs and vanilla were measured on bake days. Eggs and butter were brought to room temperature for approximately 45 minutes before use. Eggs were thoroughly combined and aliquots taken for each formula.

Order of baking was randomized and all treatments within cookie type were prepared once for each day of data collection. Each of two pans prepared per cookie type were considered one replication. Four cookies from the center of each pan were randomly assigned to sensory evaluation and instrumental evaluation (**Figure 5.1**). The cookies were stored individually in sandwich bags with a zipper-type closure (Kroger Corp., Cincinnati, OH) until evaluation, which was performed three days after baking. Three of the four center cookies from each pan (replication) were designated for evaluation by the color spectrophotometer and digital camera method. Because the tests conducted were not destructive, the same selected cookies were also used for sensory evaluations. Of the three cookies used for instrumental evaluation, one was randomly assigned for sensory evaluation in the Macbeth light booth and one was randomly assigned for sensory evaluation in the sensory booth. The fourth cookie was designated a spare and set aside in case one of the test cookies was damaged during evaluation.

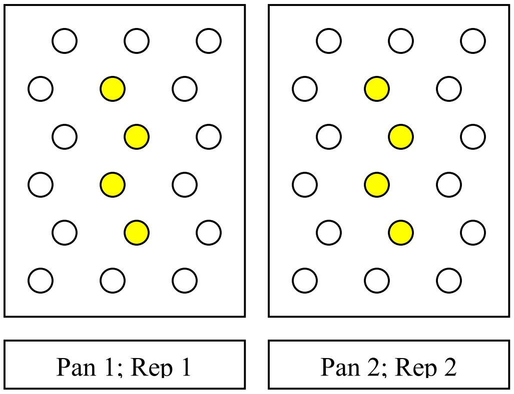

Figure 5.1. Representation of pans (replications) obtained per batch per treatment. The four center cookies from each pan were randomly assigned to sensory and/or instrumental evaluation.

Sensory Evaluation

Panelist selection

Eight to ten panelists were selected for the visual evaluations that were conducted using both the Macbeth light booth and individual sensory testing booth. The panelists had no training in color evaluation, but had prior flavor and texture sensory experience and were familiar with the use of line scales. Prior to evaluation, panelists were screened (short method) using Ishihara's Tests for Colour-Blindness (38 Plates Edition, 1991, Kanehara & Co., Ltd. Tokyo, Japan). The Ishihara plates allow quick and accurate assessment of congenital color vision deficiencies. The same panelists evaluated cookies in both sensory settings. The order in which panelists evaluated the samples in either the Macbeth light booth or sensory booth was randomized.

Development of physical references for sensory evaluation

Physical color reference cards were created to represent numerical anchors of 1, 3, 5, 7 and 9 on a 10-point light-to-dark line scale. These reference cards were used by the panelists in the Macbeth light booth evaluation and for the development of digital color references used in the sensory booth evaluation.

Cookie references, representing the cookie color range from light to dark, were first developed using the formulas presented in **Table 5.1**. The formulas were derived by modifying the FFC and RF chocolate chip cookie basic dough formulations without the inclusion of chocolate chips. One pan of each of the 5 formulas was baked and CIELAB values were collected from 5 points on the cookie surface of the center cookie from each pan using a handheld Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ). These selected cookies were then computer color-matched by Custom Color (Athens, GA), and matching latex paints (Wash'n Wear interior flat wall paint, Jones-Blair Company, Chattanooga, TN) were formulated. Color reference cards (**Figure 5.2**) were created by dipping 8-cm x 12-cm posterboard swatches in each paint. A 2.5-cm diameter circle was cut from the center of each swatch and paint was applied to the exposed edge of the circle. Swatches were dried completely in a desiccator. CIELAB values were collected for comparison with the original cookie reference from 4 positions on each swatch using the Minolta color spectrophotometer. Average CIELAB values for the cookie references and physical color reference cards are presented in **Table 5.2**. Although the cookie and paint CIELAB values differ, three experimenters verified that the resulting physical color references were good visual matches to the cookie samples under cool white fluorescent lighting and that the physical color references approximated the range of cookie color represented by the line scale. These physical reference cards were used by the panelists when assessing cookie color in the Macbeth booth.

Table 5.1. Formula and procedure[1] for reference cookies

		Corresponding Line Scale Position				
Ingredients	Product information	1	3	5	7	9
		--(g)--	--(g)--	--(g)--	--(g)--	--(g)--
All-purpose flour	ConAgra, Inc., Omaha, NB	308.6	308.6	308.6	308.6	308.6
Salt	Flavor House, United Salt Corp., Houston TX	5.5	5.5	5.5	5.5	5.5
Baking soda	PYA/Monarch, Greenville, SC	3.0	3.0	3.0	3.0	3.0
Granulated sugar	Monarch Regency, Greenville, SC	259.0	150.0	150.0	150.0	
Light brown sugar	Domino Sugar Corp., NY, NY		109.0	109.0	109.0	
Dark brown sugar	Dixie Crystals, Savannah Foods and Industries, Savannah, GA					259.0
Imitation vanilla flavor	Greinoman's/Unified Industries, Inc., Cumming, GA	4.0	4.0	4.0	4.0	10
Large, Grade A egg	Kroger Corp., Cincinnati, OH	114.0	114.0	114.0	114.0	114.0
Salted butter	Land O Lakes, Inc., Arden Hills, MN	227.3	227.3	189.3	113.0	113.0
Dried plum puree	Sunsweet Growers, Inc., Yuba City, CA			21.0	63.0	63.0

[1] Ingredients were mixed with a KitchenAid Classic mixer (model K4555, St. Joseph, Mich.) equipped with a paddle beater and baked in a Maytag oven (model MER5530AAWW, Maytag Appliances, Cleveland, OH). Flour, salt and soda were combined in a separate bowl. Butter, sugar, brown sugar and vanilla (and prune puree where appropriate) were creamed at speed 1 for 1 minute. Then beaten egg was added and mixed at speed 2 for 2 minutes. Dry ingredients were then added in 3 additions as the dough was mixed at speed 2 for 2 minutes. 17±1g of dough was scooped with a #70 scoop and placed in 6 rows down and three across on a baking sheet. Each pan was lined with parchment paper and sprayed with Pam non-stick cooking spray (International Home Foods Inc., Parsippany, NJ). Dough was gently flattened to approximately 6mm thickness and baked at 190C (375F) for 9 minutes. Cookies were cooled on the pan for 5 minutes, then removed to a wire rack to cool for at least 1 hour.

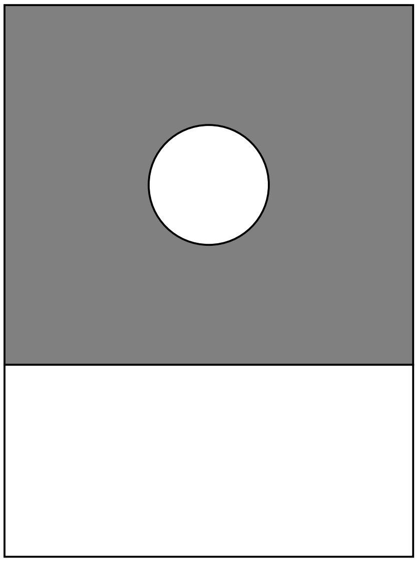

Figure 5.2. Representation of physical reference sample. Each swatch was 8-cm x 12-cm with a 2.5-cm hole to allow comparison with the cookie sample.

Table 5.2. Average CIELAB values of reference cookie samples[1] and resultant physical[2] references and RGB and CIELAB values of digital[3] references

	Reference Cookies			Physical References			Digital References					
	L*	a*	b*	L*	a*	b*	R	G	B	L*	a*	b*
Reference 1	77.90	5.93	27.64	82.24	4.99	25.29	255	241	139	94	-5	51
Reference 3	72.37	9.45	30.78	77.79	8.97	31.22	253	232	126	91	-2	54
Reference 5	58.96	14.49	33.71	60.66	11.03	30.64	202	172	79	71	3	53
Reference 7	52.04	16.22	33.59	52.41	11.57	29.38	192	156	36	65	5	67
Reference 9	40.10	16.42	25.77	44.22	12.64	23.08	168	131	58	57	8	47

[1] Cookie formulations presented in Table 5.1; CIELAB values were collected from 5 points on the surface of the center cookie from each pan. Cookies were computer color-matched by Custom Color (Athens, GA) for development of latex paints used in the creation of physical references.

[2] Physical references were created by dipping 8-cm x 12-cm posterboard swatches in each paint created from the reference cookies. A 2.5-cm diameter circle was cut from the center of each swatch. CIELAB values were collected from 4 positions on each swatch for comparison with original cookie reference.

[3] Digital color references were created in Adobe PhotoShop 5.5 (Adobe Systems Inc., San Jose, CA) using RGB mode. Using the software tools, a 2.5-cm diameter circle was created using the Elliptical Marquee tool. Circle color was adjusted using the software's Color Picker tool, with the CIELAB values obtained from spectrophotometric measurement of the physical references as a starting point. The Color Picker selection circle was moved in the RGB color space until a visual color match was obtained between the physical reference sample and onscreen image. Final adjustments to lightness/darkness were made in the LAB color space. RGB and LAB values were recorded for each of the 5 reference colors.

Macbeth SpectraLight II Light Booth Evaluation

One at a time, panelists were seated in front of the Macbeth light booth, approximately 60-cm from the cookie surface. There was no illumination in the room other than that from the light booth. The cool white setting (color temperature 4,150K) was used. A stand, covered with a 12.5-cm x 20-cm poster board card painted Munsell N/7 Standard (Sherwin Williams Latex SW1005Sylverado) to match the booth interior, was positioned at the center back of the booth interior. The stand allowed the sample to be positioned at an approximate 45° angle to the light source and an approximate 90° angle to the panelists.

The cookies were presented monadically in random order. Panelists were given a paper ballot with a 0-10 point line scale for each sample. Physical reference cards, as described above, were placed before the panelists. These cards represented 1, 3, 5, 7 and 9 on a 0 (light) to 10 (dark) line scale that represented the cookie color range. Panelists held the reference cards over the cookie, viewing the center of the cookie through the 2.5-cm hole in the reference card. The panelist's response was recorded on the line scale on the paper ballot.

Development of digital color references for sensory evaluation

Digital color references were created to represent 1, 3, 5, 7 and 9 on a 0-10 line scale that ranged from light to dark. These digital references were used by panelists in the sensory booth evaluation procedure. The goal was to create a digital (computer) image that visually matched both the cookie references and the physical color reference cards used in the evaluation of the cookies in the Macbeth light booth. A Pentium III PC, 750 MHz, 64 MB Ram with a ViewPanel VP150 (ViewSonic, Walnut, CA) monitor, equipped with a Magnum Xpert 128 video card (ATI Technologies, Thornhill, ON, Canada) was used. The monitor was calibrated using Adobe Gamma protocol (Adobe Photoshop 5.5, Adobe Systems Inc., San Jose, CA).

To create each digital color reference, a new file was opened in Adobe Photoshop 5.5 (Adobe Systems Inc., San Jose, CA) using RGB mode. Using the software tools, a 2.5-cm circle was created using the Elliptical Marquee tool. CIELAB values obtained from spectrophotometric measurement of the physical references were entered as a starting point to add color to the circle. Using Photoshop's Color Picker tool, the selection circle was moved in the RGB color space until a good visual color match as assessed by three experimenters was obtained between the physical reference card prepared for use by panelists in the Macbeth booth and the onscreen image. Final adjustments to lightness/darkness were made in the LAB color space. In this manner, 5 digital color references, equivalent to the 5 physical color reference cards, were created. RGB and LAB values were recorded for each digital color reference (**Table 5.2**). Each circle was saved as an individual .bmp file, Windows format, resolution 300 pixels/inch.

The next step was to place the digital references into the computer questionnaire for presentation in the sensory booth. Using Compusense (Compusense® *five*, release 4.0, Compusense, Inc., Quelph, Ontario, Canada), a sensory evaluation software package, the project was opened on the sensory analyst workstation and the individual .bmp files were opened in the Title and Text area (image aspect ratio 50), Question area (image aspect ratio 25) and Instructions area (image aspect ratio 75). In the Title and Text area and Question area, the circles were spaced to align with 1, 3, 5, 7 and 9 on the line scale. The Compusense background for all screens was changed to a gray similar to the Munsell N/7 Neutral background used in the Macbeth light booth. The background for the individual reference circles was adjusted to match the Compusense background using side-by-side visual monitor comparisons of Compusense and Photoshop images. To accomplish this, two monitors were attached to one computer via two matching video cards. These digital references were used by sensory panelists evaluating color in an individual sensory booth.

Sensory Booth Evaluation

A single sensory booth was used for evaluation in order to control lighting conditions. The sensory booth was approximately 80-cm wide by 51-cm deep, with its own ceiling. The booth counter was approximately 81-cm from the floor. The testing room was lit by three ceiling fluorescent fixtures. The fixture directly behind the booth used for evaluation held 4 cool Sylvania F40 Cool White, 40W fluorescent lamps (Phillips Lighting Company, Somerset, NJ) each. The two other fixtures in the testing room, to the right and left of the booth, each held 2 Sylvania F40 Cool White, 40W fluorescent lamps. Additionally, a portable fixture that held 1 cool white lamp (GE Under Cabinet 21" Fluorescent Light Fixture, GE Home Electric Products, Cleveland, OH) was suspended from the ceiling of the booth directly above the evaluation area, approximately 105-cm from the booth counter. The combination of light fixtures provided approximately 100 foot-candles of light in the comparison area immediately in front of the monitor.

Panelists were seated one at a time at a sensory booth equipped with the Compusense computerized sensory analysis system (Compusense® *five*, release 4.0, Compusense, Inc., Quelph, Ontario, Canada). Because the color of the digital images on the monitor varied depending on the angle of the viewer to the screen, a weight was suspended from the ceiling of the booth at the optimum eye-level. Under supervision of the panel leader, each panelist adjusted his/her chair until his/her eyes were at this viewing level.

Cookies were presented monadically in random order. To evaluate cookie color, the panelist held a cookie sample up to the screen and compared it with on-screen digital color reference circles, described above, that represented 1, 3, 5, 7 and 9 on a 0 (light) to 10 (dark) line scale. The line scale was also presented on the monitor. Panelists also had the option of viewing larger circles on the separate Instruction screen. The color value of each cookie was marked on the computer line scale with a mouse input device.

Instrumental Techniques

Color Spectrophotometer

A handheld Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ) was used to collect L*a*b* values from the three selected cookies from each formulation. The d/8 spherical geometry of the instrument provides for measurement with or without the specular (gloss) component included. Including the specular component is particularly useful when comparing objects with different textures (Mabon 1993). Because the cookie samples were of uniform texture, the specular component was excluded. Although the cookies used in this study were relatively small (averaging 6 cm in diameter), when viewed at the distance that a consumer may typically inspect the appearance, they occupied over 4 degrees of the field of view. Therefore, the 10-degree observer function, appropriate for viewing angles over 4 degrees, was used.

Prior to use, the spectrophotometer was calibrated using the Minolta white calibration standard (CM-A70). CIELAB values were collected using the Illuminant F6 (cool white fluorescent, color temperature 4,150 K) setting. L*, a* and b* values were collected at two points on the cookie surface (**Figure 5.3**) and averaged to provide single L*, a* and b* values per cookie. At each measurement point, the instrument took five readings and averaged the three most similar readings. Hue angle (*arctan [b*/a*]*) was calculated from the measurements.

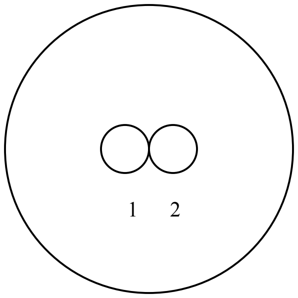

Figure 5.3. The spectrophotometer was used to collect CIELAB values from the two data points as represented above. The values were then averaged together to obtain single L*, a* and b* values for each cookie. Hue angle (arctan [b*/a*]) was calculated.

Digital Camera/Software

CIELAB values for the three selected cookies from each formulation were also determined using a modified version of the digital camera technique described by Papadakis and others (2000). A Macbeth SpectraLight II (Macbeth, Kollmorgen Instrument Corp., New Windsor, NY) light booth was used to provide cool white fluorescent illumination (color temperature 4,150 K). The booth was located in a room that could be darkened completely to avoid interference from ambient lighting. An Olympus 3000ZOOM (Olympus America Inc., Melville, NY) digital camera was positioned on a small tripod approximately 25 cm from the sample. A stand, covered with a 12.5-cm x 20-cm poster board card painted Munsell N/7 Standard (Sherwin Williams Latex SW1005Sylverado) to match the booth interior, was positioned at the center back of the booth interior. The stand allowed the sample to be positioned at an approximate 45° angle to the light source and an approximate 90° angle to the camera lens.

The digital camera was set to aperture f5.6, the setting previously used on a 35 mm camera in a study of hamburger color under the same lighting conditions (Lyon 1998). The automatic shutter speed setting used by Papadakis and others (2000) allowed the camera to make automatic adjustments based on ambient lighting. In this study, a shutter speed of 1/20s was used to avoid any adjustments by the camera. No flash was used. White balance was set to fluorescent. The macro setting, appropriate for photographing subjects at a distance of 20—78 cm, was used. Images were saved as uncompressed .tif files, 1600 x 1200 pixels.

To collect the images, the room was darkened. An image of the gray background was taken before and after the cookie photos as a self-check (**Appendix F**). One image of each cookie was recorded. Five images were collected per disk, and the .tif files were downloaded to a PC using SanDisk software (SanDisk Corp., Sunnyvale, CA). The PC was equipped with a Pentium® II Processor with MMX technology, 400 MHz processor speed and 192.0 MB RAM.

The downloaded .tif files were opened in Adobe Photoshop 6.0 (Adobe Systems Inc., San Jose, CA). The images were cropped to exclude areas beyond the width and height of the cookie using the Crop tool. Resolution for all images was 72 pixels/inch. In order to resize the image, sample width was measured. Using the Image Size menu, the sample width was entered with the Constrained Proportion option activated. Once resized to the original sample dimensions, the Elliptical Marquee tool was used to select a 2.5-cm diameter circle from the center of the cookie image. This selected area was copied to a new file and displayed in Lab mode (the asterisks are dropped in Photoshop). The Magic Wand tool was used to select the white background, and then the Select

Inverse function was used to select the cookie area. The Histogram, which graphically depicted the number of pixels at each color level, gave the mean and standard deviation of color levels displayed for L^*, a^* and b^* separately. The means and standard deviations were recorded. The following equations, adapted from Papadakis and others (2000), were used to convert the mean color levels obtained from the histograms from the 256 color levels used by the software to equivalent L^*, a^* and b^* values.

- $L^* = (L/255)(100)$
- $a^* = (240a/255)-120$
- $b^* = (240b/255)-120$

L^* ranges from 0 (black) to 100 (white). Photoshop specifies the possible range of values of a^* and b^* to be –120 to 120, although in theory a^* and b^* have no boundaries. These equations convert the 256 color levels used by the software to equivalent L^*, a^* and b^* values. Hue angle (*arctan [b*/a*]*) was calculated from the measurements.

Statistical Analysis

Results of all sensory and instrumental tests were analyzed using SAS software (SAS for Windows, version 6.12, SAS Inc., Cary, NC). PROC UNIVARIATE was used to produce normality plots for the purpose of verifying normal distribution of data. If the data lacked either variance equality or normality, it was transformed to meet the assumptions necessary for valid analysis (Cochran and Cox 1957). Mixed model of analysis of variance (PROC MIXED) was used for data analysis ($p<0.05$). Least-square means (LS MEANS) and standard error were generated. PDIFF was used for means separation (Littell and others 1996). T-tests (PROC TTEST) were performed to compare the Macbeth evaluation method to the sensory booth method and to compare the color spectrophotometer to the digital camera/software method ($p<0.05$). Relationship between methods was analyzed (PROC CORR) with the Pearson's Product Moment correlation statistic ($p<0.01$).

Results and Discussion

Sensory Methods

Results of both sensory evaluation methods are presented in **Table 5.3**. For both cookie types, panelists scored the full-fat control significantly lighter in color than the modified cookie formulas according to the fixed effects model. This was expected due to the partial replacement of shortening and/or butter with a considerable amount of prune puree in the modified formulas. There was a small but statistically significant difference in sensory scores for the RF and RFS CC cookie formulations in both evaluation methods. The difference between the formulas may simply be due to the variability in position and amount of chocolate chips within the individual samples used for evaluation. Alternatively, the panelists may have had difficulty evaluating the heterogenous cookie matrix using a homogenously colored reference card. No differences were found between the modified (RF and RFS) OAT formulas.

T-test comparison (PROC TTEST) of both sensory methods indicate they were similarly effective in identifying differences between the formulations and yielded comparable lightness intensity scores with significant differences ($p<0.05$) between the methods found only for CC FFC and RF formulas. Again, this may be attributable to position and amount of chocolate chips within the individual samples. During the Macbeth evaluation, panelists were instructed to compare only the center of the cookie to the reference, whereas the entire cookie was used for comparison with the digital

Table 5.3. LS-Means (±SE) and Pearson's Product Moment correlation coefficients[1] for sensory scores of chocolate chip and oatmeal cookies.

		Macbeth Score[2]	Sensory Booth Score[3]	Correlation Coefficients Between Methods
Cookie Type	Treatment	LS-Means ± SEM	LS-Means ± SEM	
Chocolate Chip	FFC†	2.88±0.16a	3.48±0.18a	r=0.9717 p=0.0012
	RF†	5.48±0.16b	6.15±0.18b	
	RFS	6.52±0.16c	6.86±0.18c	
Oatmeal	FFC	3.83±0.20a	3.60±0.31a	r=0.977 p=0.008
	RF	7.26±0.20b	7.27±0.31b	
	RFS	7.71±0.20b	7.37±0.31b	

[1] r=correlation coefficient; p=significance level. Correlations between sensory methods within cookie type are across 8-9 panelists by 2 replications within cookie type.

[2] Panelists were seated at the Macbeth light booth, which provided the only illumination (color temperature 4150K) in the testing room. Each cookie sample was positioned at an approximate 45° angle to the light source and an approximate 90° angle to the panelist. Physical references represented 1, 3, 5, 7 and 9 on a 0 (light) to 10 (dark) line scale. Panelists scored the cookies on a paper ballot.

[3] Panelists were seated in a sensory booth equipped with the Compusense computerized sensory analysis system (Compusense® *five*, release 4.0, Compusense, Inc., Quelph, Ontario, Canada). Cool white fluorescent tubes provided illumination. Panelists held individual cookie samples up to the digital display and compared them with on-screen reference colors that represented 1, 3, 5, 7 and 9 on a 0 (light) to 10 (dark) line scale.

[abc] LS-Means within a column and cookie type followed by different letters are significantly different ($p<0.05$). Mixed model of analysis of variance (PROC MIXED) was used for data analysis and PDIFF was used for means separation (Littell and others 1996). Means are across 8-9 panelists by two replications within cookie type.

†T-test comparison (PROC TTEST) indicates significant differences ($p<0.05$) between sensory assessment methods within treatment. Means are across 8-9 panelists by two replications within cookie type.

reference in the sensory booth evaluation method. The portion of the sample evaluated may impact sensory color perception when evaluating heterogeneous products.

Correlation analysis was conducted to determine if the sensory methods were linearly related. The results indicate a strong relationship between the scores obtained by both methods and suggest that either method would generate comparable results in visual color evaluation. Light booths such as the Macbeth SpectraLight II provide several illuminant options and do not require calibration. However, they are costly and permit evaluation by only one panelist at a time. Further, selection and maintenance of existing physical references or creation and standardization of custom color references may be a cumbersome task. The sensory booth method may prove to be a more economical and flexible means of color evaluation in many testing situations. This method uses easily accessible equipment and permits simultaneous evaluation by multiple panelists. After initial monitor calibration and installation of appropriate lighting, digital references can be easily created and customized to the project at hand. Panelists may require some supervision however; as the angle at which the panelists view the monitor may affect the apparent on-screen color.

Instrumental Methods

Results of instrumental evaluation are presented in **Table 5.4**. Generally, differences found by both instrumental methods reflect the difference in product formulation due to modification. The FFC formulas of both CC and OAT cookie types had significantly higher L* values (were lighter), lower a* values (were less red), higher b* values (were more yellow), and larger hue angle values.

According to the fixed effects model (PROC MIXED), no significant differences between modified CC formulas were found with the color spectrophotometer. However, small but significant differences between the modified CC formulas in L* and hue angle were found with the digital camera method, as previously reported for both sensory assessment methods. The lower L* value may reflect the increased relative density of chocolate chips in the RFS formula as bulk is lost as a consequence of sugar replacement. It may also simply reflect the averaging of color across a 2.5-cm diameter area of the cookie surface, which would include varying relative amounts of chocolate chips on the

Table 5.4. CIELAB values and hue angle[1] of chocolate chip and oatmeal cookies and Pearson's Product Moment correlation coefficients[2] with significance level between instrumental measurement methods

Cookie Type	Analysis Method	Treatment	Color Attributes (LS-Means ± SE)			
			L*	a*	b*	Hue Angle
CC	Color Spectrophotometer	FFC	65.6942±1.0978b	3.2233±0.1943a	31.6760±0.5382	83.9596±0.3536b
		RF	51.3878±0.1036a	6.5900±0.1943b	31.9892±0.4913	78.3604±0.3550a
		RFS	48.8375±1.0978a	7.1250±0.1943b	31.7992±0.4913	77.3922±0.3536a
	Digital Camera/Software	FFC	49.3836±0.4960c	3.4014±0.1602a	38.7937±0.4158b	85.0004±0.3000c
		RF	31.8824±0.4993b	10.4568±0.1636b	33.7349±0.4158a	72.7711±0.3047b
		RFS	29.4119±0.4960a	11.0574±0.1602b	32.2588±0.4158a	71.0878±0.3000a
	Correlation Coefficient		r=0.99500 p<0.0001	r=0.99397 p<0.0001	r=-0.84628 p=0.0336	r=0.99618 p=0.0001
OAT	Color Spectrophotometer	FFC	58.1458±0.6465b	4.4067±0.1119a	30.5750±0.4391b	81.8344±0.1709b
		RF	41.3467±0.6465a	6.7708±0.1092b	26.9542±0.4391a	75.9441±0.1689a
		RFS	42.6758±0.6465a	6.8269±0.1092b	26.9808±0.4391a	75.8007±0.1689a
	Digital Camera/Software	FFC	41.7922±0.3427b	6.7198±0.1350a	37.7804±0.3065b	79.9155±0.1911b
		RF	21.0209±0.3427a	9.0683±0.1339b	23.7835±0.3065a	69.1385±0.1911a
		RFS	21.1804±0.3427a	9.3670±0.1339b	23.9545±0.3065a	68.6355±0.1911a
	Correlation Coefficient		r=0.99604 p<.0001	r=0.98613 p=0.0003	r=0.97008 p=0.0013	r=0.99961 p<0.0001

[1] CIELAB values measured using a Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ) and Olympus 3000ZOOM (Olympus America Inc., Melville, NY) digital camera/Adobe Photoshop 6.0 (Adobe Systems Inc., San Jose, CA); hue angle was calculated (arctan [b*/a*]).

[2] r=correlation coefficient; p= significance level. Correlation values between analysis method and instrumental color attributes are across 18 samples per cookie type and across all treatments.

[abc] LS-means in a column within an analysis method followed by different letters are significantly different ($p<0.05$). Mixed model of analysis of variance (PROC MIXED) was used for data analysis and PDIFF was used for means separation (Littell and others 1996).

sample surface. This would not have been captured by the ‘point’ measurement of the color spectrophotometer. No significant differences between the modified OAT formulas were found using either instrumental method.

For the CC cookies, T-test comparison (PROC TTEST) of the two instrumental methods indicated significant differences ($p<0.05$) between all color values except FFC formula a* and hue angle values and RFS formula b* values. T-tests on the OAT cookie data revealed significant differences ($p<0.05$) between all color values obtained within this cookie type. Correlation analysis was conducted to determine if there was a linear relationship between the two methods. Correlation coefficients greater than $r=0.9$ are typically considered indicative of confidence in the instrumental assessment (Gaines 1994). The results indicated a strong linear relationship between the two methods, suggesting that the digital camera method is able to identify relative color differences and may be suitable for quality control and other situations in which less precise analysis is required.

Although costly, the color spectrophotometer has several advantages: it provides precise color measurement, offers both standard observer functions and multiple illuminant options, and is easy to calibrate and use. However, the color spectrophotometer provides only a ‘point’ measurement; it may be difficult to obtain an accurate and meaningful assessment of heterogeneous samples using this instrumentation. The digital camera method is relatively inexpensive compared to the color spectrophotometer, although it does require a certain level of computer literacy. It provides a permanent record of the sample appearance and allows flexibility in selection of the area of the image to be analyzed. These advantages may be important in quality control and in research applications where identification of relative color differences is more important than precise quantification of CIELAB values. For heterogeneous products in which the background matrix is markedly different from distinct, identifiable novelty ingredients such as chocolate chips, Photoshop color assessment procedures may need to be modified to obtain a more accurate evaluation of color. In this study, the matrix and chocolate chips were averaged by Photoshop. In practical applications, this blending of distinct phases may not correspond well with human color evaluation. Additional information about how consumers evaluate color of heterogeneous products may be helpful. If consumers evaluate the matrix and ingredients as separate entities, the software's flexibility allows for selection of user-defined areas of the image and would allow independent evaluation of the matrix and any novel additions. Because the area selected is visible on the computer screen, it is easier to control the exact location desired for assessment of distinct phases than is possible with the spectrophotometer.

Correlations Between Sensory and Instrumental Measurements

Correlation analysis (**Table 5.5**) was conducted to determine if the sensory and instrumental measures of color were linearly related. Generally, these results show very strong relationships between both sensory and both instrumental methods within cookie type. Negative correlations between sensory scores and instrumental L* values can be attributed to the difference in scales used. The sensory line scale ranged from light (0) to dark (10) whereas instrumental values of L* can range from 0 (black) to 100 (white).

Conclusions

All color evaluation methods tested provided satisfactory assessment of product color. The applicability of the sensory and instrumental methods depends on the specific application and the desired endpoint. The strong correlations between the instrumental and sensory results validate the ability of both instrumental methods to provide meaningful color data.

Table 5.5. Pearson's Product Moment correlation coefficients[1] with significance levels between sensory methods[2] and instrumental methods[3] for chocolate chip and oatmeal cookies

			Instrumental Methods							
			Digital Camera/Software				Color Spectrophotometer			
Cookie Type	Sensory Method		L*	a*	b*	Hue Angle	L*	a*	b*	Hue Angle
CC	Booth	r	**-0.98948**	**0.9884**	**-0.97976**	**-0.99049**	**-0.98644**	**0.98453**	0.82443	**-0.98576**
		p	**0.0002**	**0.0002**	**0.0006**	**0.0001**	**0.0003**	**0.0004**	0.0435	**0.0003**
	Macbeth	r	**-0.97757**	**0.96355**	**-0.99376**	**-0.97503**	**-0.98759**	**0.98482**	0.78955	**-0.98733**
		p	**0.0007**	**0.002**	**<0.0001**	**0.0009**	**0.0002**	**0.0003**	0.0618	**0.0002**
OAT	Booth	r	**-0.971**	**0.94061**	**-0.97468**	**-0.96756**	**-0.96274**	**0.97518**	**-0.91852**	**-0.97011**
		p	**0.0012**	**0.0052**	**0.001**	**0.0016**	**0.0021**	**0.0009**	**0.0097**	**0.0013**
	Macbeth	r	**-0.99248**	**0.98997**	**-0.99251**	**-0.99614**	**-0.98113**	**0.99442**	**-0.96086**	**-0.99521**
		p	**<0.0001**	**0.0002**	**<0.0001**	**<0.0001**	**0.0005**	**<0.0001**	**0.0023**	**<0.0001**

[1] r=correlation coefficient; p= significance level; bold values indicate significance at $p<0.01$

[2] Correlation values are across 8-9 panelists and 3 formulas with 2 replications within each cookie type. Sensory scale ranged from 0 (light) to 10 (dark).

[3] n=18 across 3 formulas per cookie type. CIELAB values measured using a Minolta Color Spectrophotometer (Model CM-508d, Minolta Co. Ltd., Ramsey, NJ) and Olympus 3000ZOOM (Olympus America Inc., Melville, NY) digital camera/Adobe Photoshop 6.0 (Adobe Systems Inc., San Jose, CA); hue angle was calculated (arctan[b*/a*]).

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CHAPTER VI

CONCLUSIONS

Experiment 1—Storage

The storage characteristics of three treatments of two cookie types (oatmeal and chocolate chip) were investigated using a trained sensory panel for flavor and texture analysis and probing for instrumental texture analysis over a 7-day period. The cookies were prepared using an alternative sweetener blend (acesulfame-K/dextrose blend) and/or prune puree to replace 50% of the sugar and/or fat, respectively.

Cookie formulations were developed by Swanson and Munsayac (1999) and Perry (2001). For both cookie types, the reduced-in-fat (RF) and reduced-in-fat and sugar (RFS) versions incorporate prune puree as a fat replacer at the levels recommended by the California Dried Plum Board (1999). Half of the initial amount of added fat in the full-fat control (FFC) formula was removed from the formulation and 25% of this initial amount was replaced with prune puree. Sugar replacement with an acesulfame-K/dextrose blend (Sweet One®) was also made according to manufacturer's recommendations (Sweet One® 1998). For both types of RFS cookies, half of the granulated sugar in the FFC formulation was removed and replaced based on the following equivalency: 16.6 grams granulated sugar was replaced by 1 gram of Sweet One®.

The shelf life of a product is broadly defined as the amount of time required before a product exhibits unacceptable physical, chemical, microbiological or sensory characteristics (Gacula 1975). The term staling focuses on the sensory characteristics of the product and is the progressive non-microbial deterioration of quality of baked products resulting in decreased consumer acceptance. The degree of staleness is determined primarily by sensory evaluation, based on smell, taste, touch and appearance (Bechtel et al. 1953). However, it is possible to detect some of the textural changes that accompany staling instrumentally and correlate them with sensory evaluation results. A valid method of instrumental evaluation of texture would reduce some of the time and expense associated with sensory evaluation (Meilgaard and others 1999).

Flavor and texture differences were identified by the trained descriptive sensory panel between the full-fat control and modified formulas of both cookie types, as expected (Perry 2001). Statistically significant storage and treatment x storage interactions were found. However, these differences were within a very narrow range of the 15-point scale, suggesting minimal effects of sugar and/or fat reduction on sensory flavor and texture characteristics. Although statistically significant, the practical significance of these differences to the consumer should be investigated.

Both cookie types exhibited significant increases in water activity over the storage period and the chocolate chip cookie type exhibited significant treatment x storage interactions. Water activity values did not indicate increased susceptibility to microbial growth. However, water activity levels of both cookie types at nearly all storage days were conducive to lipid oxidation reactions. Off-flavors and odors were not specifically evaluated by the sensory panel; further study is needed to determine if the use of additional evaluation terms would allow detection and identification of the effects of lipid oxidation over the storage period.

Probe results indicated significant texture changes in the oatmeal cookie type over the storage period for all probe parameters reported. Generally, the modified formulas tended to become more similar to the full-fat control over the storage period. Few significant changes in probe parameters were found in the chocolate chip cookie type over the storage period.

The oatmeal cookie type showed highly significant correlations between both area parameters and sensory evaluation of manual hardness and oral hardness ($r=0.596$—0.765, $p<0.0001$) and between average slope and sensory evaluation of manual fracturability and oral fracturability ($r=0.798$—0.806, $p<0.0001$). Fewer significant correlations were found between sensory and instrumental results for the chocolate chip cookie type ($r=0.430$—0.628, $p<0.002$—0.0001). The lack of strong correlations in this cookie type may be due to the interference of the chocolate chips. Generally, correlations between manual determinations of textural attributes and probe results were stronger than were those between oral determination and probe results. This may reflect the wetting of the product by saliva that occurred during oral evaluation.

Consumer acceptability of these cookies 1 day post-bake has been shown previously (Perry 2001). In general, the cookies exhibited few significant changes over time, indicating that the shelf life of the modified cookies is similar to that of the full-fat control under the same storage conditions. In this study, it was not possible to analyze samples from each batch on every storage day due to baking and panel schedule constraints. It may be desirable to do so in future studies, and to assess consumer acceptability over a reasonable storage period. Further, it was not technically feasible to produce a full-fat, reduced sugar version of either cookie type using acesulfame-K, despite manufacturer recommendations. The use of other non-sucrose sweeteners or sweetener blends and alternative fat replacers and their impact on shelf stability should be investigated.

Experiment 2—Color

Appearance, including color, plays a significant role in consumer response to products (Setser 1984). Food color also provides flavor and safety cues. Color specification is important in quality control applications as well as product development and modification (Hutchings 1999). Flexible, reliable and convenient methods of sensory evaluation and instrumental measurement are needed. It is critical that instrumental measurements are reflective of human sensory perception (Setser 1984).

In this study, three treatments of two cookie types (oatmeal and chocolate chip) were utilized to evaluate the effectiveness of two sensory color evaluation techniques (Macbeth booth and sensory booth methods) and two instrumental color measurement methods (spectrophotometer and digital camera method).

For sensory evaluation using the Macbeth booth method, panelists were seated in front of a light booth with cool white fluorescent illumination. Panelists compared samples to color reference cards representing 1, 3, 5, 7 and 9 on a 10-point light-to-dark intensity scale and marked their response on a paper ballot. For sensory evaluation using the sensory booth method, panelists were seated in a standard sensory booth equipped with a computer monitor. Panelists compared samples to digital color references representing 1, 3, 5, 7 and 9 on a 10-point light-to-dark intensity scale and marked their response on the line scale using the computer mouse. Both sensory evaluation methods investigated in this study proved similarly successful in identifying color differences in the cookies due to modification. Correlation analysis indicated a strong, highly significant relationship between the two methods (oatmeal—r=0.977, p=0.008; chocolate chip—r=0.972, p=0.001). However, the heterogeneous nature of the chocolate chip formulations did appear to influence the results. This may have been due to variability in position and amount of chocolate chips in the cookies, or the panelists may have found it difficult to compare a heterogeneous product to a homogenous reference.

A handheld spectrophotometer was used to collect CIELAB values from the samples. Cool white fluorescent illuminant (F6) setting and the 10° observer functions were used. For the digital camera method, images of the samples were recorded with a high-resolution digital camera under cool white fluorescent illumination (provided by the Macbeth booth). Images were downloaded to a PC, opened in a graphics software package and color levels of the center section of the cookies were recorded and converted to CIELAB values. Both instrumental evaluation techniques investigated also proved successful in identifying color differences due to modification, although they did not yield similar CIELAB values according to t-test results. However, correlation analysis indicated a strong, highly significant linear relationship between the two methods (oatmeal—r=0.99, p<0.0001; chocolate chip—r=0.99, p=0.0001).

Both instrumental evaluation methods have advantages and disadvantages. The spectrophotometer is precise, easy to use and offers several measurement options, but is costly and can only provide ‘point’ measurements. The digital camera method does require standardized lighting conditions and computer software, but allows measurement of a variable, user-determined area of the product and provides a permanent record of the product appearance. This ability may also allow areas that contain novelty ingredients, such as chocolate chips, to be avoided if desired.

The strong linear relationships between sensory and instrumental data indicated by correlation analysis ($r=0.98$-0.99, $p<0.002$) validates the merit of both instrumental techniques. Further study is needed to assess the impact of different lighting conditions and the application of these techniques to other products, in particular, other heterogeneous foods.

References

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