**Author:** **Jamal, Khalid**

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**STUDENT**:

**NAME: Jamal, Khalid** **DATE: 01-Aug-2016**

**ADVISOR:** (Committee Chair if MS Plan A or EdS Thesis or Field Project/Problem):

**NAME: Eun Joo Lee, Ph.D.** **DATE: 01-Aug-2016**

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**Jamal, Khalid V.** ***A Comparison of Baking Quality Characteristics and Texture of Soft Cookies Made with Sucrose and Splenda®***

## Abstract

Sucrose tenderizes cookies during baking and delays gelatinization by absorbing the liquid. Sucrose is also responsible for the baking quality and texture of the cookie. Using sugar substitute products such like Splenda® is a great way to reduce the calories in baked goods, but it can be an effect on cooking baking quality and texture. Thus, the objective of this study was to compare the baking quality characteristics and texture of soft cookies made with sucrose and Splenda®. Cookies were made by using the American Association of Cereal Chemists (AACC) procedure. Texture analysis studies were conducted using the TA.XT2 plus texture analyzer. The cookie hardness of the cookie dough was measured using the compression test and the breaking strength of the baked cookies was measured by the puncture test. The effects of sugar substitute on cookie baking quality characteristics were studied by cookie's set time, diameter, height compared with control. The results showed that the replacement of sugar with Splenda® have a significant effect on cookie texture, strength, and height ($p<0.05$). Baked cookie diameter does not have significant effect ($p>0.05$) after replacing sugar with levels of Splenda® (25%, 50%, 75% and 100%).

**Acknowledgements**

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# Chapter I: Introduction

Consumer demand for low-calorie baked products including cookies has been increasing and manufacturers have developed low-calorie sweeteners such as Splenda® that may deliver the functionality of sugar. Non-caloric sweeteners are used as sugar replacements in cookies and baked goods with reduced caloric product formulations (Struck, Jaros, Brennan & Rohm, 2014). However, sugar plays a very significant functional role in the baking quality (cookie spread, diameter and height) and texture of the finished product (Doescher, Hoseney, & Milliken, 1987). Reducing or replacing sugar with non-caloric sweeteners may have an effect on cookie baking quality characteristics and texture. A challenge to the product developers is the loss of functionality due to sugar replacement primarily associated with texture (Zoulias, Oreopoulou, & Kounalaki, 2002).

## Statement of the Problem

There is an emerging consumer demand for low-calorie baked products including cookies. This is largely achieved by replacing sugar with non-caloric sweeteners (Zoulias et al., 2002). Therefore, from a manufacturing standpoint, the effect of replacement of sugar with Splenda® on cookie baking quality characteristics and from a consume prospective, the effect on finished cookie texture needs to be understood. Also, partial replacement with Splenda® may strike a balance between finished cookie texture.

## Purpose of the Study

The purpose of this study was to compare the baking quality characteristics and texture of soft cookies made with sucrose and the commercially available non-caloric sweetener Splenda®.

## Assumptions of the Study

The assumptions of the study were:

1. The study used texture analysis as a primary basis to assess quality characteristics of baked cookies. Texture is assumed to be the most important quality parameter that may change when sucrose is partially (or fully) replaced with Splenda®. The breaking strength is calculated using breaking force. In addition, the finished cookies diameter, height and set time were considered to be effective dependent variables and important quality parameters for assessment in the product development cookies made with low or non-caloric sweeteners to determine baking quality.
2. The study used the formulation for a standard sugar cookie (American Association of Cereal Chemist, 2010). It is assumed that this formulation is the best available model system to study the defined objectives.

## Definition of Terms

The definitions of the following terms are:

**Amino acid.** A compound consists of amino ($-NH_2$) and carboxylic acid (-COOH) functional group.

**Gluten.** A mixture of protein found in wheat and related grain such as rye.

**Maillard browning.** A reaction between amino acid and reducing sugar.

**Protein.** A large molecule consists of at least one chain of amino acid.

**Reducing agent.** In a chemical reaction, a compound losing electron.

**Reducing sugar.** A reducing sugar act as a reducing agent because it consists of aldehyde and ketone group. Such as, all monosaccharides.

## Limitations of the Study

This study could not represent the sensory evaluation and color measurement of cookies due to the time restraints in producing this product in a laboratory setting. Texture results are based on the texture analyzer equipment TA.XT2.

## Methodology

Non-caloric sweetener Splenda®, sugar and all other ingredients was purchased from the local store. All the ingredients were mixed using Hobart mixture and then placed on a baking sheet in the oven. Cookies were baked for 10 minutes at 400°F. After baking, cookies were cooled for 3 hours and then cookies diameter and height was measured. Compression force to compress the dough by 80% was recorded. Puncture test technique was used to measure the breaking strength. Cookie dough set time was measured to observe at which point cookie dough stop expansion (Hosney, Wade & Finley, 1988). Cookies were removed at a 1-minute interval until the finished baking time to measure the cookie set time (Jacob & Leelavathi, 2006). Statistical analysis was done using one-way ANOVA at $p<0.05$.

# Chapter II: Literature Review

This chapter will begin with an overview of cookies and the functionality of cookie ingredients. The chapter will then discuss the chemistry and the functionality of Splenda® with an emphasis on previous research conducted using Splenda® as a sugar replacement. The variables used for measuring cookie quality will be discussed with specific emphasis on baking quality measurements and texture.

## Cookies

Cookies are a popular packaged food in the United States. A survey from 1995 showed that 45% of Americans bought cookie at least once a month (Malovany, 1995). In 1998, the market for baked cookies was up by 15% from the previous year. In 2000, the market value of cookies sold was $4.5 billion (Sosland, 2000). For the year 2012 the reported revenue was $11.7 billion.

The term cookie refers to a baked product containing a high percentage of sugar relative to water (Faridi, 1994). The high concentration of sugar in cookies can be altered to provide a spectrum of cookie types. Depending upon the formulation, up to 40% of sugar does not dissolve before baking. Cookies are dissimilar from breads and cakes because of the high sugar to flour ratio (Table 1).

Table 1

*Formula for Sugar-Snap Cookie*

| Ingredient | Weights (g) |
|---|---|
| Flour | 40 |
| Sucrose | 24 |
| Nonfat dry milk | 1.2 |
| Sodium bicarbonate | 0.40 |
| NaCl (in solution B) * | 0.18 |
| Ammonium chloride (in solution B) * | 0.20 (in 2 mL) |
| Shortening | 12 |
| Sodium bicarbonate (in solution A) ** | 0.32 (in 4 mL) |

*solution B was prepared by dissolving 88.8 g sodium chloride and 101.6 g ammonium chloride, in 1 L of distilled water, **solution A was prepared by dissolving 79.8 g sodium bicarbonate in 1 L of distilled water (American Association of Cereal Chemists, 2010)

Around 360 different cookie products were introduced in the United States market in 2001 (Roberts & Dornblaser, 2002). However, these new products often lacked satisfactory quality and texture and efforts are currently underway to improve these characteristics. Since fat and sugar are the major contributors to cookie texture and quality characteristics, removing these components can have a significant effect on consumer liking of these reformulated products.

The three basic ingredient components in cookies are dry (i.e., flour and sugar), liquid (i.e., fats and water) and minor ingredients (i.e., leavening agent). The cookie product process begins with the mixing of ingredients followed by dough relaxation for 30 to 45 minutes. During dough relaxation stage the dough is transferred into transfer tubs for the high speed mixed

mixers. Following relaxation, the dough is placed in hoppers for machining. The three basic machines used to produce cookies in industry are rotary mold, extrusion and laminating. After machining, the formed and shaped cookie dough is moved to the baking lines, typically using conveyer belt systems. Almost all commercially baked cookies are currently baked in travelling or band ovens which are 100 to 300 feet in length and 25 to 100 inches wide. Cookies coming off these ovens are cooled in cooling conveyers. Following cooling, the products are packed in retail/consumer use packages.

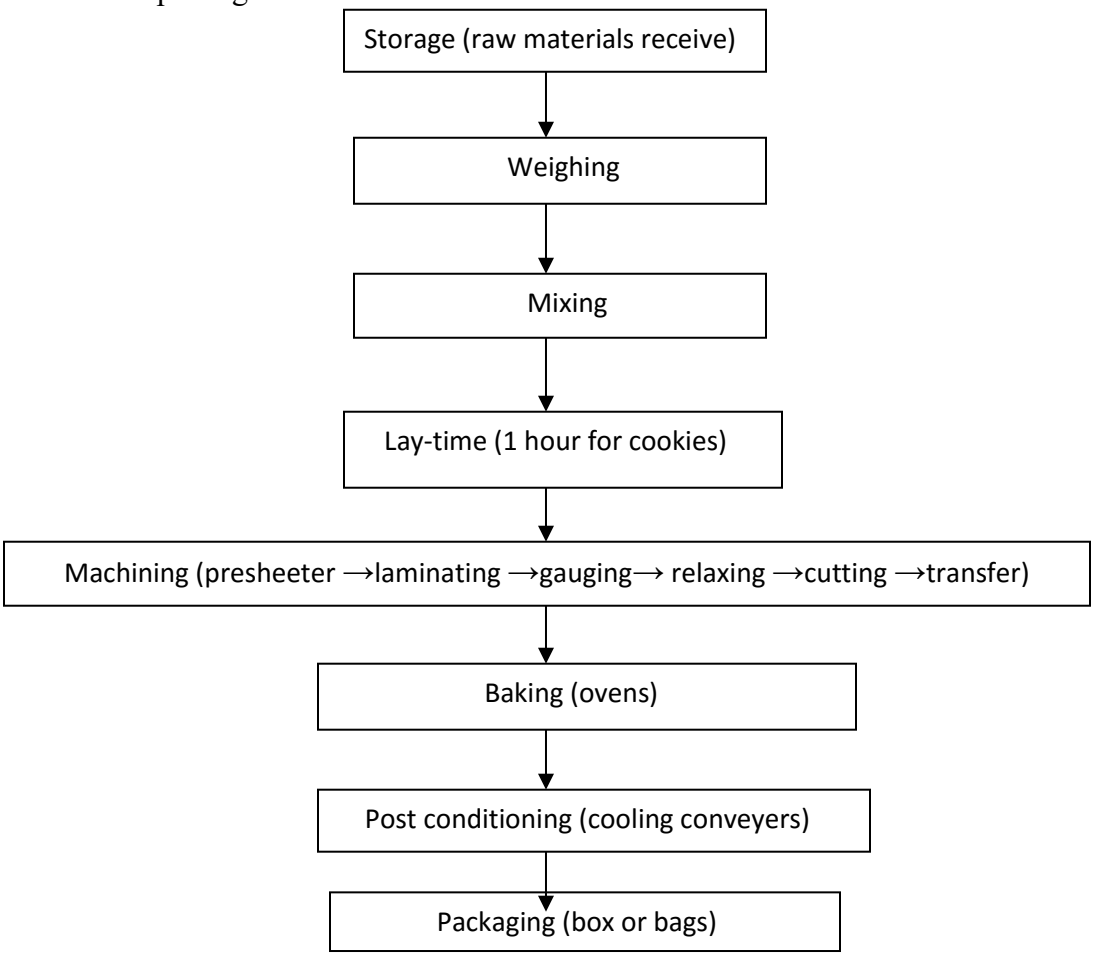


*Figure 1.* Flow chart for cookie manufacturing in commercial level.

**Ingredients in cookie formulation.** According to the American Association of Cereal Chemists (AACC, 2010), 10-52 sugar-snap cookie preparation method contains only 2.7 mL of water content (based on 14% moisture base flour), and cookies are typically containing high

amount in fat and sugar. In cookie dough, starch and gluten present in the flour compete with the sugar for water. The fat and sugar hinder gluten development and starch gelatinization, resulting in a tender finished product. Cookie formulations containing higher percentages of water result in softer textures.

***Sugar.*** Sugar facilitates the development of the sweet taste of food products and also delivers caloric energy, bulk, taste and texture. In general, the term sugar is commonly associated with sucrose (table sugar). However, the term sugar designates all monosaccharides and disaccharides such as glucose, fructose and sucrose. Chemically, the carbohydrates that are monosaccharides and disaccharides are known as sugars. In one molecule of a monosaccharide, three to six carbon atoms are present in a ring type structure. Glucose, fructose and galactose are the main monosaccharides in human nutrition (Figure 2) (Groff & Gropper, 2000). In one molecule of a disaccharide, two monosaccharide monomers are joined together by glycosidic linkages. Sucrose with isomaltose, lactose and maltose are the main disaccharides (Figure 2).

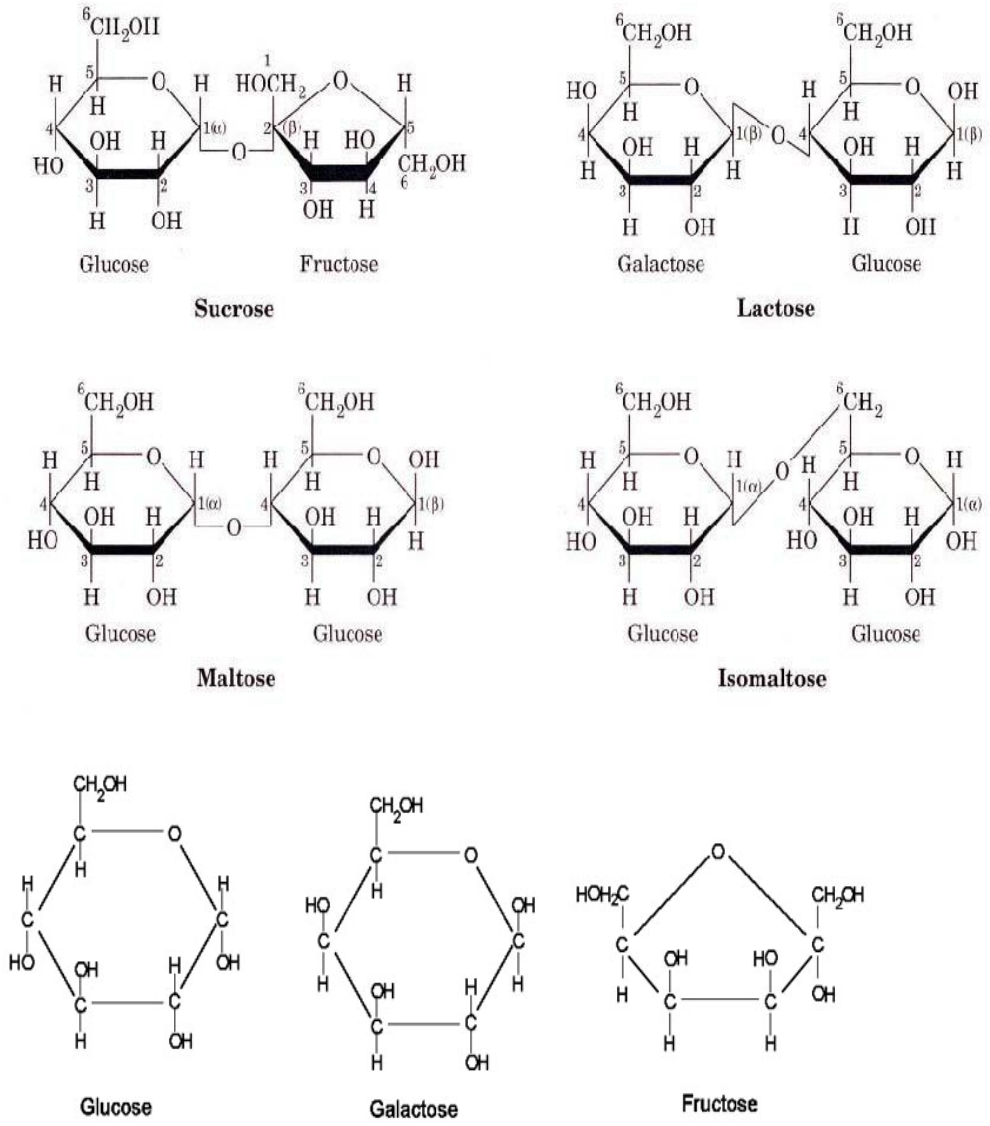


*Figure 2.* The chemical structures of monosaccharide and disaccharide carbohydrates. (Groff & Gropper, 2000)

α-glucose and β-fructose join together to form one molecule of sucrose. β-galactose and α- or β-glucose are joined together to form lactose. α-glucose and α or β-glucose are joined together to form one molecule of maltose, and when two glucose units are linked together, one molecule of isomaltase is formed.

Unlike sucrose, in reducing sugars a free aldehyde group present in sugar undergoes oxidation and yields carboxylic acids such as disaccharide lactose and maltose.

In the process of baking cookies, sugar has significant functional properties. The hydroxyl group present in the sucrose molecule confers hygroscopic properties on the molecule resulting in the absorption of water at high levels of relative humidity. Sugar decreases the growth of microorganism and different chemical reaction by decreasing the amount of free water (Davis, 1995; Fontana, 2000). By non-enzymatic browning, sugar generates good flavor and appearance in cookie baking (Penfield & Campbell, 1990). Sugar also provides bulk in a baked cookie.

When any dough is made, gluten strands form during mixing due to the hydration of proteins in the flour. $CO_2$ gas generated in this process fills the pockets created by gluten resulting in stretching of the dough. Excessive amount of gluten can make the dough tough and rigid. The addition of sugar in dough formulations slows gluten development by absorbing water. Therefore, in cookie dough, complete development of gluten is not possible because sugar continuously competes with flour proteins for the limited quantity of water thereby resulting in cookies that are tender rather than tough and rigid.

The hardness of cookies (in dough and the baked product) is largely due to the development of the gluten (protein) network. Sugar reacts as a tenderizer by absorbing moisture, which is important for the gluten network development. Sugar delays starch gelatinization because it is hygroscopic and hinders gluten development. Therefore, hardness of the dough can be a part of the solubility of the sweeteners (Zoulias et al., 2002).

During baking, the quick rise in the viscosity of sugar is responsible for cookie spread and increasing amount of sugar increased cookie spread (Hoseney & Miller, 1997). During

baking, the temperature of cookie dough rises and dough viscosity drops due to the dissolution of sugar (Hoseney & Miller, 1997). In soft cookies, hygroscopic sugars such as sucrose are used. Storage and packaging are also important considerations for the retention of moisture and to control cookie texture during storage. Cookies made with low molecular weight sugar will harden if stored under low humidity conditions (Hoseney & Miller, 1997).

Drewnowski, Nordensten, and Dwyer (1998) reported results based on different cookie formulation, sugar and fat to give 25% decrease in sugar, fat, both sugar and fat, and a 50% decrease in fat. Reducing sugar in cookies by 25% resulted in the most consumer satisfaction. This observation shows that consumers are less sensitive towards fat reduction. A very small quantity of sweeteners is essential as a substitute for sucrose. As a result, properties of baked product are altered with a change in the amount of high concentration sweeteners.

In the formulation of reduced sugar cookies, bulking agents like maltodextrin are essential to reimburse the loss of bulk due to the reduction in the amount of sugar. Maltodextrin is used as filler that compensates for the loss in volume. Maltodextrin also raises the gelatinization temperature of starch (Nonaka, 1997). Maltodextrin from different sources has dissimilar properties compared with the gelatinized forms because of the starch sources (Nonaka, 1997). Starch structure varies with the source. For instance, potato starch has nearby 79% amylopectin, while wheat has about 72%. Furthermore, starch is largely comprised of two main polymers with dissimilar structures. Amylose demonstrates mostly a linear association, comprising glucose connected by 1-4 bonds, while amylopectin is extremely branched.

***Wheat flour***. Wheat is the main grain used in cookie flour. There are three collective species of wheat grown in the United States. Join (*Triticum aestivum*) and club (*Triticum compactum*) wheats, are generally used to make wheat flour. The third type of wheat, durum, is

used to make macaroni products. Wheat can also be classified on the basis of the surface color of the kernel (white and red), planting season (winter or spring), and whether the surface of kernel is hard or soft.

In wheat flours, the concentrations of ash, lipid, protein and carbohydrate are different. Ash concentrations are under 0.5% (12% moisture basis), and lipid concentrations are under 2%. There are two kinds of protein in flour, gluten proteins and water-soluble proteins. The gluten protein is the dominant protein and is responsible for dough properties including stretching and forming. Albumins and globulins are water-soluble proteins that comprise 10-15% of the total protein content. Flour quality is also influenced by the enzymes α-amylase, β-amylase and the proteolytic and oxidative enzymes. In comparison to α-amylase, β-amylase is present in high quantities and is deactivated at low temperatures. Proteolytic and oxidative enzymes present in flour contribute to flour bleaching. In comparison to whole wheat flour, white wheat flours have a higher concentration of carbohydrates and low levels of protein, ash and lipids.

In flours, starch is mainly in the form of carbohydrates. Starch molecules are polymers of glucose. In a starch molecule, glucose is a hexose because it is a sugar with six carbon atoms. Glucose molecules present in both aldehyde and pyranose (ring) structures in a solution. There are two classes of starch synthesized by plants. In class one, two α-D-glucose molecules are connected through the first carbon of one molecule and the fourth carbon of a different molecule, giving rise to a molecule of maltose. In the other class, three molecules of maltose are combined together and form a triose. Chains of these glucose residues are known as dextrins. When the glucose components in a molecule range from a few thousand to a million, the large polymers are called starch. When glucose residues are combined through the 1, 4-linkages as in maltose, this kind of linear starch molecule is called amylose. When several α-1,4 connected short chains

of 15 to 30 glucose residues branch off on the α-2,4 main sequence amylopectin is produced. Generally, starch granules are comprised of nearby ¼ amylose and ¾ amylopectin molecules. Moreover, there are a small number of plants that cover more amylose than amylopectin, such as high amylose cornstarch or amylomaize. An accurate composition of wheat samples collected in the U.S. during one crop year is shown in Table 2.

Table 2

*Ranges of Major Components in U.S. Wheat*

| | Range of Analytical Result, % | |
|---|---|---|
| Determination | Low | High |
| Protein | 7 | 18 |
| Ash | 1.5 | 2 |
| Lipid | 1.5 | 2 |
| Starch | 60 | 68 |
| Cellulose | 2 | 2.5 |
| Moisture | 8 | 18 |

The revised method of AACC 10-52 for sugar-snap cookie method is useful in calculating flour category. The technique calculates the overall value of soft wheat flour for manufacturing modern cookies. The method is also useful to evaluate other flour kinds. Table 3 illustrates the weight of flour at numerous moisture contents equivalent to additional water for the cookie test formula (AACC, 2010).

Table 3

*Weights of Flour at Several Moisture Contents*

| Flour Moisture (%) | Added Water (g or ml) | Flour Weight (g) | Flour moisture (%) | Added Water (g or ml) | Flour Weight (g) |
|---|---|---|---|---|---|
| 9.1 | 4.9 | 37.8 | 12.1 | 3.6 | 39.1 |
| 9.2 | 4.9 | 37.8 | 12.2 | 3.5 | 39.2 |
| 9.3 | 4.8 | 37.9 | 12.3 | 3.5 | 39.2 |
| 9.4 | 4.7 | 38.0 | 12.4 | 3.4 | 39.3 |
| 9.5 | 4.7 | 38.0 | 12.5 | 3.4 | 39.3 |
| 9.6 | 4.6 | 38.1 | 12.6 | 3.3 | 39.4 |
| 9.7 | 4.6 | 38.1 | 12.7 | 3.3 | 39.4 |
| 9.8 | 4.6 | 38.1 | 12.8 | 3.3 | 39.4 |
| 9.9 | 4.5 | 38.2 | 12.9 | 3.2 | 39.5 |
| 10.0 | 4.5 | 38.2 | 13.0 | 3.2 | 39.5 |
| 10.1 | 4.4 | 38.3 | 13.1 | 3.1 | 39.6 |
| 10.2 | 4.4 | 38.3 | 13.2 | 3.1 | 39.6 |
| 10.3 | 4.3 | 38.4 | 13.3 | 3.0 | 39.7 |
| 10.4 | 4.3 | 38.4 | 13.4 | 3.0 | 39.7 |
| 10.5 | 4.3 | 38.4 | 13.5 | 2.9 | 39.8 |
| 10.6 | 4.2 | 38.5 | 13.6 | 2.9 | 39.8 |

(AACC, 2010)

Sugar-snap cookies spread during baking and are also influenced by the composition of flour types. Cookies made with good-quality cookie flour exceed its original size significantly, while poor quality flour results in a spread that is significantly smaller (Hoseney & Miller, 1997). Thereby commercial cookies are prepared from soft wheat flours.

The difference between soft and hard wheat flour is the higher ratio of protein to starch. Soft wheat flours are used for cookies for multiple reasons: (1) once hard wheat is milled more of the starch is impaired; (2) during baking, soft wheat flour gives greater cookie spread; (3)

Cookies made from hard wheat flour are less tender in comparison to cookies made from soft wheat flour; (4) In the finished baked cookie product, soft wheat flour provides a soft and powdery texture, while hard wheat flour results in a hard texture. The hardness of hard wheat flour is attributed to larger stability of the protein conditions within the cells and the complex arrangements of starch granules (Hoseney & Miller, 1997).

***Fat.*** Fats are triglycerides of fatty acids. In a fat molecule, three fatty acid molecules are chemically joined with one glycerol molecule to yield one molecule of lipid that could have varying structures. The melting points of fats with different structures are different. Crystallization properties are also dependent on fatty acid chain length and degree of unsaturation, positional specificity and heterogeneity. Positional specificity exists in triglycerides because the second carbon in the glycerol chain is asymmetric (Figure 3).

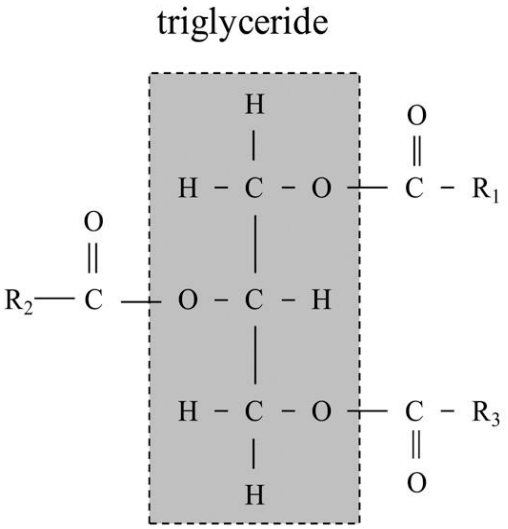


*Figure 3.* The structure of a triglyceride molecule. The shaded region is the glycerol and R1, R2 and R3 are fatty acids. (Innis, 2011)

According to the American Association of Cereal Chemists (AACC) 10-52 sugar-snap method, the ratio of fat and sugar is 1:2. Fat contributes necessary physical characteristics by aerating the batter. Fat results in functional and sensory characteristics in cookies by providing

creaminess, lubricity and a good appearance (Akoh, 1998). Fats have a lubricating outcome that yields a sensation of moistness in the mouth. Fat produces and uniformly distributes leavening gases throughout the creaming process, producing air cells. In cookie baking, leavening gas enhances the bulk of a product by causing the cells to grow. Fat also tenderizes the product by inhibiting the gluten development. In cookie baking, fat imparts desirable characteristics and increases consumption by facilitating aeration, contributing to flavor, promoting texture, interacting with starch components to alter hydration, affecting swelling properties and acting as an emulsifier. Fats modify the physical and chemical properties of cookie dough to manage these products more proficiently. During cookie baking, fat provides grease to the core structure of intermediates to permit greater growth under the effect of leavening gases and creates a more tender baked product. Since any ingredient used as a fat replacer must be hydrated, cookie products that are made with reduced fat usually have a larger quantity of water than those made with full fat (Clark, 1994).

Zoulias et al. (2002) showed that textural properties in cookies differs significantly and depends on fat type and quantity. The author used Raftiline, Simplesse, C*delight and polydextrose as fat mimetics. The amount of fat used in cookies is an important factor and has a significant effect on the finished cookie structure (Abboud, Rubenthaler, & Hoseney, 1985). Abboud et al. (1985) showed that flour weight affects significantly on cookie shape. The author showed that an irregular shape was obtained by decreasing the weight up to 25% and finer top grain by increasing the fat weight from 30 to 35%.

***Cookie baking additives.*** In sugar cookies, baking additives can include salt, baking powder and non-fat dry milk. The quantity of salt depends on the baked cookie formulation and varies from 1% to 2.5% of the flour weight. Salt affects the rheology of dough by modifying the

physical properties of gluten. Salt functions as a binding agent in the cookie dough. An optimum amount of salt generally improves the crumb color and grain. In addition to salt, baking powder is also used as a baking additive.

Baking powder is formed when baking soda or sodium bicarbonate ($NaHCO_3$) combined together with dried acid. During baking, baking soda releases carbon dioxide ($CO_2$).

$$2\ NaHCO_3 + heat \rightarrow Na_2CO_3 + CO_2 + H_2O$$

Baking powder facilitates the release of carbon dioxide. Carbon dioxide is a major contributor to the leavening process and helps in dough expansion during baking. During baking, baking powder releases $CO_2$ and is known to increase cookie spread.

Nonfat dry milk is another ingredient in cookie manufacturing. Whey powder is a substitute for nonfat dry milk. Nonfat dry milk has some advantages when compared to whey powder because it has good nutritional characteristics and a long shelf life (Doerry, 1989). Nonfat dry milk has ambivalent effects on the structure of dough as it strengthens the gluten network.

**Types and Classification of Cookies**

In different kinds of cookies, large differences in composition can occur. Cookies classification is mainly based on method of production. Cookies contain high amounts of sugar and fat and can be processed by (1) rotary-mold, (2) wire-cut, or (3) bar-press processors (Faridi, 1994). Rotary mold cookies contain a low amount of water (approximately 20%). The dough is cohesive only after pressure has been applied. An example is the sandwich type, OREO®. The wire-cut cookie method produces a much softer cookie, and these cookies have been studied extensively. Examples include sugar-snap, chocolate-chip, or oatmeal cookies. Moreover, most of the work reported in the scientific literature relates to the procedure of sugar-snap cookies

because it is easily reproducible. Bar-press cookies are not popular. These are extruded as a continuous log or ribbon of dough and generally cut after baking.

**Splenda®**

Splenda® is the brand name that contains non-caloric sweetener sucralose, a chlorinated derivative of sucrose. In 1991, the safety of sucralose and permission to use in food and beverages was first approved by Canada's Health Protection Branch. In 1998, the United States Food and Drug Administration (FDA) approved the use of sucralose in certain food products. In 1999, FDA extended the approval and permitted sucralose to use as a multipurpose sweetener.

**Chemistry and functionality in baked goods.** Splenda® is composed of sucralose, which is blended with the inert ingredient maltodextrin. The sweetness of Splenda® comes from the sucralose. The taste profile of sucralose is similar to sugar, and its profound ability to remain stable at high temperature allows for use in the food processing industry and baking. Sucralose is 600 times sweeter than sucrose.

The chemical name of sucralose is 1,6-dichloro-1,6-dideoxy-β-D-fructofuranosyl-4-chloro-4-deoxy-α-D-galactopyranoside (Figure 4). Sucralose is derived from sucrose through a mbvfive step procedure that replaces three hydroxyl groups of sucrose with chlorine atoms. The resultant molecule of sucralose contains three molecule of chlorine. These replacements create the different molecule that is extremely stable to both enzyme hydrolysis and acid (Sham, 2005).

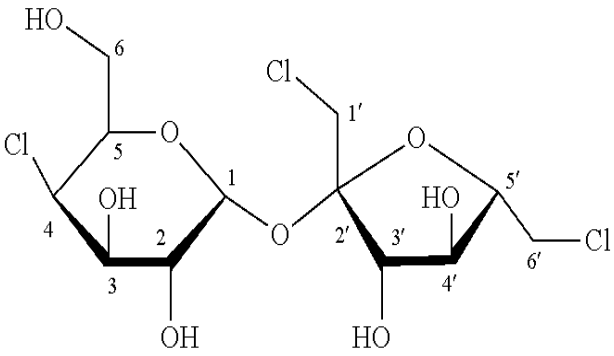


*Figure 4.* Chemical structure of sucralose. (Splenda®, n.d)

In the past 20 years, more than 110 scientific research has been conducted using sucralose (Sham, 2005). Sucralose is preferred in baking over other artificial sweetener because: (1) its taste profile is very similar to sugar because it is made from sugar, (2) stable at high temperatures, (3) it is not metabolize, (4) no clinical evidence related to the unsafety of sucralose consumption (5) it has a better aftertaste, (6) sucralose does not chemically relate with other food components and does not change in the presence of ethanol, (7) ability to preserve 99% sweetness after one year (Sham, 2005).

Maltodextrin provides bulk in Splenda® to measure out cup-for-cup like sugar (Nonaka, 1997; Sham, 2005). Maltodextrin is prepared by the partial hydrolysis of starch with enzymes or acids. Maltodextrin forms weak gels and as a result the reaction between amylose parts categorized by helical areas which is separated by the lined chains of amylopectin molecules (Chronakis, 1998). Maltodextrin is composed of fine particles and is made from carbohydrate sources, such as corn. It yields 4 cal/g.

Maltodextrin can function as a fat mimetic in flour-based mixes or in baking systems. The starch molecule undergoes acid or enzymatic hydrolysis or a combination of both and splits the molecule into reduced and unsystematic length chain. These polysaccharides propose many health benefits to product developers and consumers, such as offering more effective reducing

water activity in a reduced-fat formula compared to protein based substitute, showing hydrophilic activity in a chemical reaction, being easily consumable in the metabolic process, being less expensive and available in grocery stores, and not requiring FDA approval because they are GRAS (generally recognized as safe) substance.

Maltodextrin functions as a texturizer and inhibits sugar crystallization. In Splenda® sucralose is blended with maltodextrin so that some of the bulk lost may be replaced when sucrose is removed from a product. Maltodextrin is a derivative of starch formed by the acid or enzymatic hydrolysis reaction. In dextrose equivalence (DE), the hydrolysis of starch in maltodextrin produces up to 20 dextrose units of changing polymer lengths. According to the FDA's 21 Code of Federal Regulations Sec.184.1444, maltodextrin is a "non-sweet nutritive saccharide polymer consists of D-glucose units linked primarily by (alpha)-1, 2 bonds and that has a DE of less than 20." The molecular weight is inversely proportional to DE. During baking, maltodextrin functions by helping in the moisture mechanism, having soluble sugar particles with a low molecular weight, lowering water activity and significantly reducing freezing points. The higher molecular weight and the low DE maltodextrins bind with water and enhance solids without these properties. Moreover, few long chain polymers do not liquefy and may actually bind water by forming a gel. Meanwhile they appear cloudy because units of these properties are subject to the product's DE. However, for the period of storage, maltodextrins, like starch, will retrograde, discharging water and causing syneresis (Kuntz, 1997). In its dry form maltodextrin produces 4 kcal/g, but when maltodextrin is hydrated, stirred and cooled a thermo reversible gel is formed, providing only 1 kcal/g. Maltodextrin is useful in reduced sugar foods because it binds and controls water, humectancy, builds solids and contributes a smooth mouth feel. Water is a component of all foods that contributes to physical differences among the

changes food undergoes (Penfield & Campbell, 1990). A food product's water activity can be reduced in the presence of water-binding bulking agent like maltodextrin.

In bakery products such as cookies, maltodextrin contributes in texture, retains moisture, increases viscosity and provides some of the characteristics of fat without enhancing the sweetness of the product (Nonaka, 1997). Maltodextrins are suitable for high-temperature products because they have a very low content of reducing sugar where Maillard reactions from excessive browning for higher DE-carbohydrates cause adverse effects on the baked product. For the dry mixes, maltodextrin adds certain attributes including flavors, colors and vitamins. It also maintains 70% relative humidity and can be used as a bulking agent. Maltodextrins are also utilized as a carbohydrate source and help to maintain caloric concentration and osmolality. Additionally, maltodextrins prevent lactose and ice-crystal formation as well as the development of graininess and a loss of quality. Maltodextrins can contribute to the melt characteristics of the product. As sugars on equivalent weight basis, their higher molecular weight does not lower the freezing point and act as cryoprotectants in frozen products. In sugars, such as glucose, it provides lower osmolality by lowering DE products. It does not contribute to sweetness but maltodextrin provides calories, so higher quantities of maltodextrin can be used to maintain calories in the body.

Savita, Indrani, and Prakash (2008) showed that the replacement of sugar with increasing amounts of maltodextin from 10 to 40% and 0.05% of sucralose has an effect on the wheat flour dough rheology. The spread ratio was 7.1 with 10% maltodextrin, 7.8 with 20% maltodextrin, 9.4 with 30% and 10.5 with 40% in comparison to the control of 9.9 with 30% sugar. These results show the possibility of replacing sugar with sucralose and maltodextrin because the quantity characteristics of the sucralose and maltodextrin are comparable to the 30% sugar. In

addition, sweetness was also acceptable. Moreover, the strength of the dough as indicated by farinograph stability and extensograph area was similar to the control at 30% maltodextrin. However, diameter of the control was 52.4 mm, and it decreased to 47.6 mm when sugar was replaced with 10% maltodextrin and indicated a gradual change with the further increase in maltodextrin up to 40% (Figure 5).

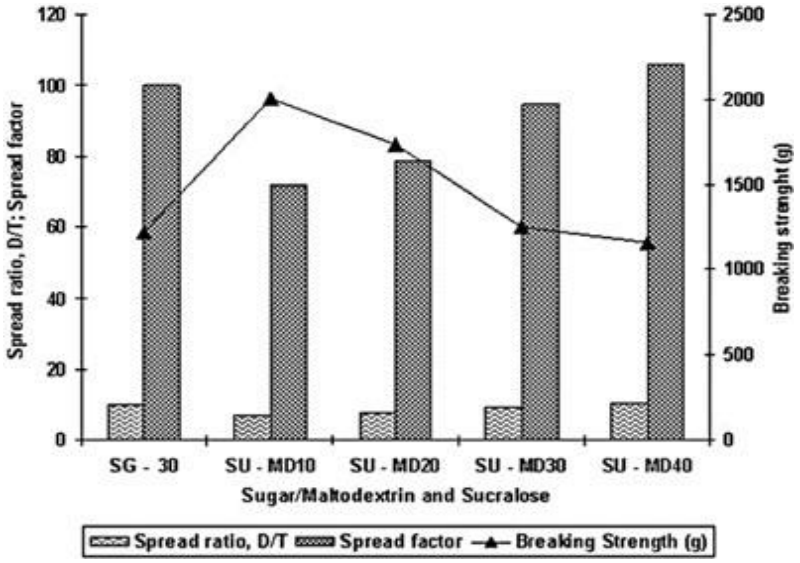


*Figure 5.* Effect of different percentages of maltodextrin (MD) and 0.05% sucralose (SU) on spread ratio, spread factor and breaking strength of wheat flour. (Savita et al., 2008)

**Rheology**

Rheology is the study of the flow of matter in a liquid or semi-solid state. The rheological properties such as elasticity and pliancy are not present in cookie dough. However, cookie dough is cohesive because large quantities of sugar and fat permit gluten network development during dough mixing (Hoseney & Miller, 1997). The tenderness in cookies can be achieved using short dough only if the amount of gluten development is kept to a minimum. It is necessary to carry out the mixing process to two or three phases for less gluten development. In rotary-molded cookies, the dough is pressed into molds on a rotating roll. As the roll finishes a

half turn, the dough is removed from the hollow and shifts into the baking oven belt. The dough flows evenly and fills the entire roll hollow's gaps without altering form. During baking, rotary molded dough must also be essentially cohesive, which means that dough spread and growth should generally be decreased. The resultant dough has no elastomeric characteristics, and the rheological this dough is viscoplastic. In wire-cut cookies, the dough obtained is significantly cohesive to grip together on the belt. Cookies contain high amounts of sugar and fat but are low in water based on flour weight. Rheological properties of cookie dough are affected by flour, sugar and fat and have an effect on texture and baking quality characteristics of the finished product (Abboud et al., 1985).

**Effect of flour on dough rheology.** Flour moisture, protein, starch and ash content have significant effects on dough rheology. Flour moisture content is not constant; changes of moisture content have significant effects on dough consistency. Also, damaged starch has an effect on dough during mixing. More suitable flour has small amount of water absorption and starch damage.

**Effect of sugar on dough rheology.** The amount of sucrose has a significant effect on a cookie's dough rheology. During mixing 40% of sucrose remains undissolved due to the lack of adequate water. The undissolved sucrose dissolves when the dough is heated in the oven. When sucrose dissolves during baking it significantly increases the volume and makes the dough very sticky (Hoseney et al., 1997). Abboud et al. (1985) showed that there is no difference in cookie diameter by altering the sugar level from 10% to 60%.

**Effect of fat on dough rheology.** Like flour and sugar, fat is also a major component in most cookie formulations. During the aqueous phase of dough mixing, fat competes for the surface of the flour particles with other ingredients. The melting properties of the fats used in the

cookie formulation are effective to dough rheology. When dough sections are made, the melting temperature of fat describes its solid content at a given temperature. In baking, uniform temperature is necessary during several cookie processing steps because dough temperature effects on cookie spread. When the fat level is high, a small quantity of water is required to accomplish dough stability. The type of fat used also has an effect on cookie dough (Abboud et al., 1985). The author showed that doughs containing oil had a slightly larger diameter in the finished product.

## Cookie Baking Quality Characteristics

The baking quality characteristic parameters are cookie spread during baking, cookie diameter and height.

**Cookie spread diameter and height.** Cookie dough when heated spreads at a rate likely control by the viscosity of the heated environment. A study showed that spreading occurs until a certain molecular action "sets" the structure, producing a sudden increase in dough viscosity (Doescher et al., 1987). Jacob and Leelavathi (2006) observed this phenomenon by cutting the cookie dough 4.5 cm in diameter and removing a cookie from the oven at one minute of intervals until the final baking time. These results are shown in Figure 6. They found that cookies prepared with different fats had different set times.

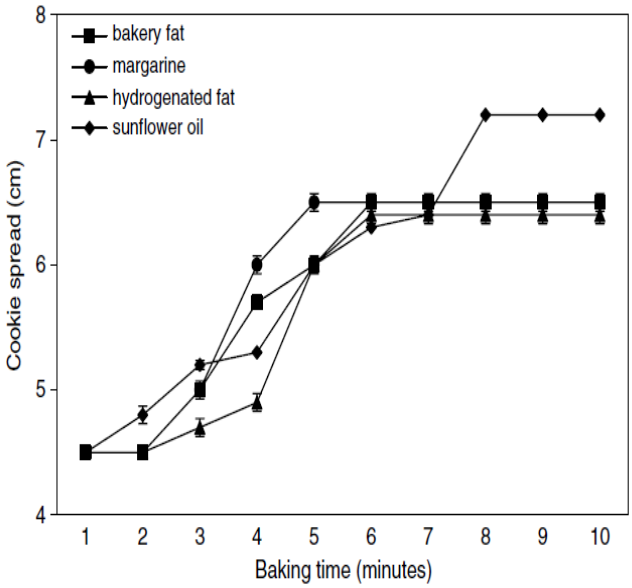


*Figure 6.* Effect of fat type on cookie spread. (Jacob & Leelavathi, 2006)

**Cookie diameter and height.** During cookie baking, gluten present in the flour forms a collapsible film as a replacement for an elastic network, and as a result, cookie diameter increases and height decreases. The concluding diameter of the cookie is an outcome from high spread rate and delayed set time. Cookie diameter and height are dependent on the contact between endogenous composites within the flour and preparation constituents. The sugar-snap cookie preparation creates a competition for water mainly between arabinoxylans, broken starch and protein portions. The preparation should be stable so that alterations in flour arrangement are exposed by the test and the appropriateness of a specific wheat variety or flour proportion for cookie baking becomes clear. Bettge and Kweon (2009) showed that cookie height is closely linked to cookie diameter and is usually seen as a redundant variable. The author found a significant correlation between cookie diameter and cookie height, $r = 0.94$.

## Texture

For determining the texture factors, instrumental measurements and sensory evaluation methods are utilized in the food industry for new product development. To industrialize a new food product texture, understanding the desired texture quality is necessary from a manufacturing stand point. Tests that comprise biting or chewing are widespread because these tests produce numerous outcomes. Overall food texturometer first produced the texture profile analysis method (Szczesniak, 1963) and later modified to the instron and TA.XT2 plus analyzer universal testing machine.

**Uniaxial compression.** In food products like cookies, it is necessary to measure the texture from consumer prospective. Certain benefits of mechanical measurements are lack of fatigue and ease of calibration within and between numerous instruments. Uniaxial compression is one of the most widespread techniques for testing the hardness of a food product. Uniaxial compression is normally shown on a form of tool recognized as a TA.XT2 plus analyzer (Figure 7). A TA.XT2 plus analyzer consists of upper and lower loading points and a load cell. A number of additional tests can be achieved on a TA.XT2 plus analyzer using several fixtures including puncture, tension and shear that permits specific and perfect control and measurement of deformation and force.

*Figure 7.* Photograph of texture analyzer model TA.XT2. (Texture Technologies, n.d)

A uniaxial compression procedure is usually used as a means to obtain force-deformation data in food textural studies. Cullen-Refai, Faubion and Hoseney (1988) performed uniaxial compression on fermenting doughs. The author showed that uniaxial compression technique provides descriptive analysis of different dough treatments (Figure 8).

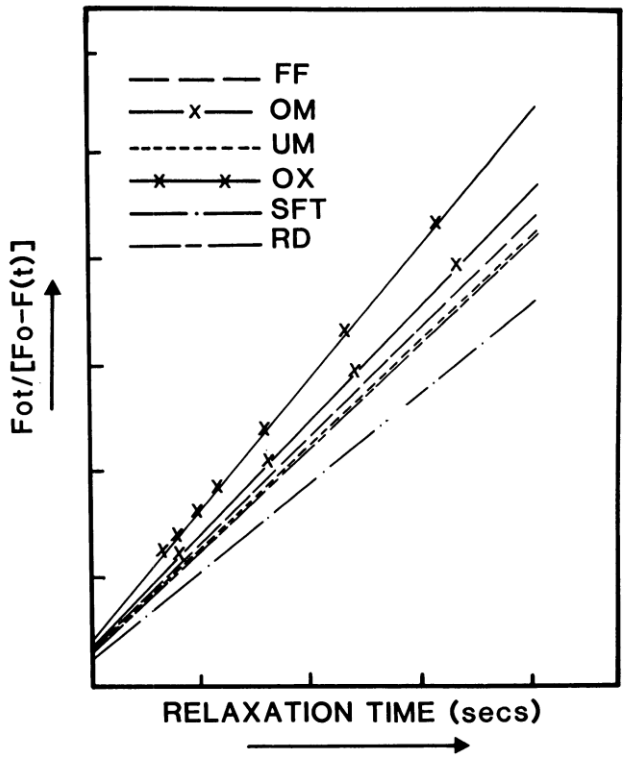


*Figure 8.* Linear transformations of stress relaxation curves obtained from fermented doughs. The doughs tested included full fermentation (FF), overmixed (OM), undermixed (UM), oxidized (OX), reduced (RD) and short fermentation time (SFT). (Cullen et al., 1988).

Uniaxial compression test for solid foods can be divided into nondestructive and destructive. In nondestructive, there is no cracker additional irreversible destruction to the sample by adjusting the compression for a smaller size. In destructive compression, the compression force causes the irreversible damage to the food products.

**Puncture test.** In puncturing test, when a punch is applied, five different types of force-distance curves from the instrument such as Instron or TA.XT2 (Figure 9).

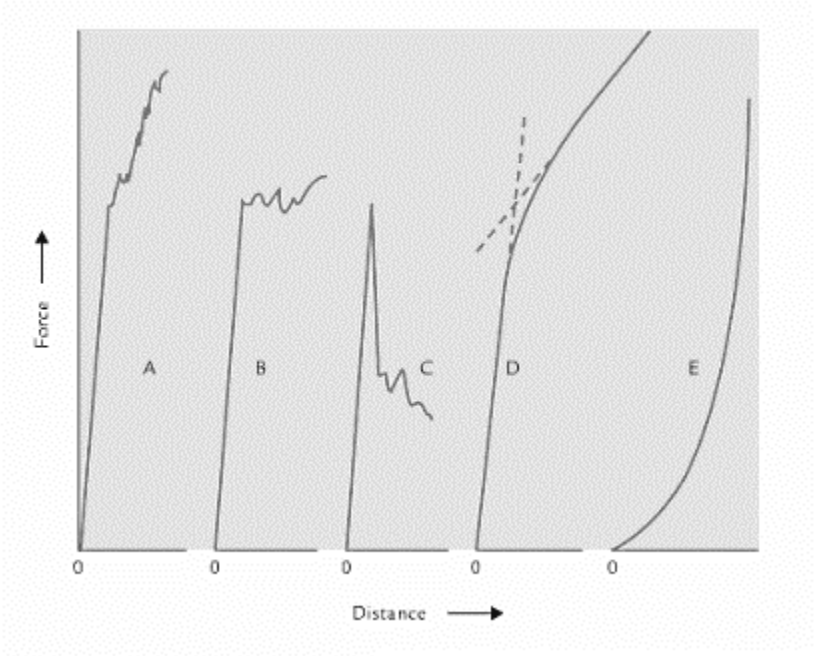


*Figure 9.* Five different curves of a puncture test. (Bourne, 1979b)

Slope changes, when punch initiate to penetrate the food product. The point at which the slope changes is called yield point. In type A, there is a sharp yield point but it does not affect the force and force continue to puncturing the food product. In type B, force does not change after the yield point. In type C, there is a sudden decrease in force after the yield point. In type D, the yield point is not sharp. In type E, there is no yield point.

A puncture test is based on semi-infinite geometry. In semi-infinite geometry for the puncture test, a sample size is very large as compare to the punch.

In the puncture test, depending on product base support is necessary to maintain balance because incorrect support may bring errors (Figure 10). A solid support is necessary when punch penetrates a small distance in the large food (Figure 10a).

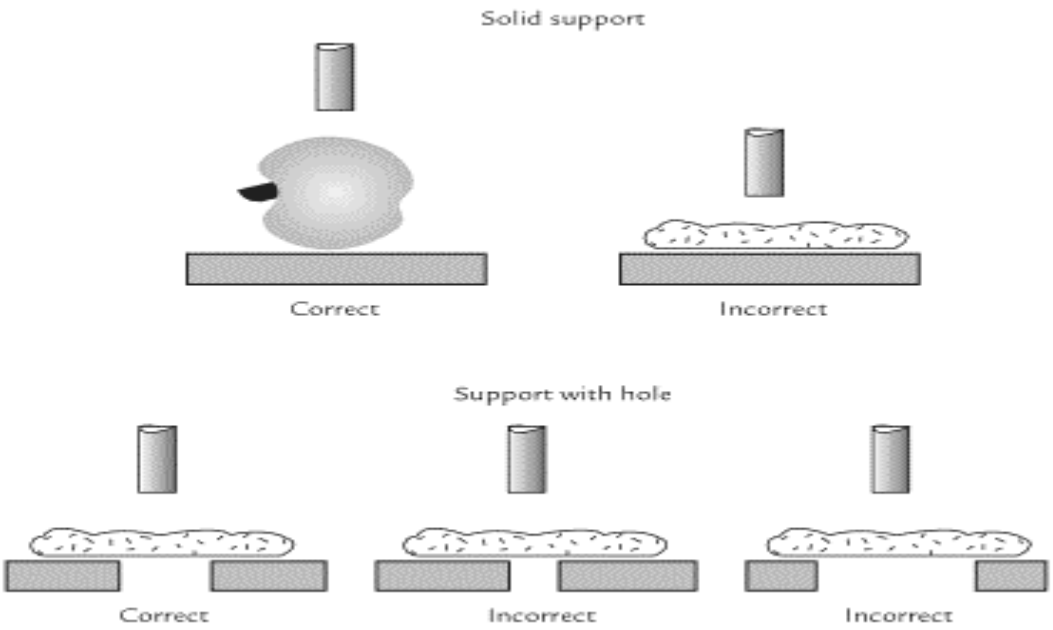


*Figure 10.* Correct or incorrect representation for puncture test. (Bourne, 1982)

A solid support is not required for the thin food specimen (Figure 10b). For the thin specimen, a support plate that has a hole in it centered under the punch is required (Figure 10c). It is necessary to avoid the same diameter of punch as hole (Figure 10d) and a very large hole as compare to punch (Figure 10e).

Puncture test allows the distribution of textures within specific foods. Jacob and Leelavathi (2006) showed that cookies prepared with different types of fat affected the cookie's breaking strength.

# Chapter III: Methodology

The purpose of this study was to define the effect of replacement of sugar with Splenda® on the baking quality characteristics and texture of cookie. This chapter will describe the different treatments were used and the methodology to prepare the cookie, parameters of texture analyzer and methodology to measure cookie's set time, diameter and height.

## Treatments

Two cookie products, sugar cookies and alternative sweetener (Splenda®) cookies, were tested using the formula in Table 1. Baking parameters (e.g., mixing time and baking times) did not vary between the two products. The regular sugar in the products was replaced with Splenda® at levels of 25%, 50%, 75% and 100% and compared with control.

## Cookie Preparation and Baking

The baking test used in this study is the approved 10-52 sugar-snap cookie baking method (AACC, 2010). Five different samples were made using different levels of Splenda®. The control sample only contains sugar. The second sample contained 25% of Splenda® with the remaining ingredients were same. The third sample contained 50% Splenda®, and the fourth and fifth samples contained 75% and 100% Splenda®, respectively. In the first step of cookie baking all dry ingredients (sucrose, nonfat dry milk, sodium bicarbonate) were sifted together eight times. A Hobart mixer was used for creaming these ingredients with shortening (Crisco, non-trans fat type) on low speed for one minute. Ingredients were then scraped from both the bowl and paddle; on medium speed for one minute, then scraped; on high speed for 30 seconds, then scraped; and on high speed for 30 seconds. The cookie dough mass was scraped into a mixing bowl. Added water 2.7 g based on 14% moisture basis of flour (AACC, 2010). Added 2mL of solution B and 4mL of solution A and then mixed for three minutes and scraped with a

spatula. Flour was added to the mixing bowl and mixed for 25 seconds. Cookie dough was sheeted to a height of 0.7 cm using a rolling pin and cut with a round cutter (6.0 cm diameter). All samples were weighed and then placed on a baking sheet in the oven. The cookies were baked for 10 minutes at 400° F in a reel-type oven for sugar and Splenda® cookies, respectively. The height and diameter of baked cookies were measured after 3 hours of cooling.

**Texture Analysis of Cookies**

The breaking strength was measured using the puncture test technique by TA.XT2 Plus Texture Analyzer with a probe of 2 mm diameter and a crosshead speed of 0.5 mm/sec. Parameters for puncturing test are reported in Table 4.

Table 4

*TA.XT2 Settings for Texture Measurement for Cookies for Puncture Test*

| | Puncturing |
|---|---|
| Test mode | Return to start |
| Pre-test speed | 1.00 mm/sec |
| Test speed | 0.5 mm/sec |
| Post-test speed | 10 mm/sec |
| Distance | 2 mm |
| Trigger | Auto |
| Force | 5 g |
| Distance | Mm |
| Force | Newton |
| Probe | 2 mm diameter cylinder |

The textural characteristics of cookie dough were measured in TA.XT2 Plus Texture Analyzer using uniaxial compression. The crosshead speed was 0.17 mm/sec. Texture was measured by a 2.5 cm diameter cookie dough pieces and 1 cm height. The force required to compress the dough by 80% was recorded. The experiment was conducted at ambient temperature. Parameters for compression test are reported in Table 5.

Table 5

*TA.XT2 Settings for Texture Measurement for Cookies for Compression Test*

| Uniaxial compression | |
|---|---|
| Test mode | Return to start |
| Pre-test speed | 3.00 mm/sec |
| Test speed | 0.17 mm/sec |
| Post-test speed | 10.00 mm/sec |
| Target mode | Strain |
| Strain | 80% |
| Trigger type | Auto (Force) |
| Trigger force | 10.2g |
| Probe | TA-25, 2” Dia cylinder |

**Baking Quality Measurements**

There is a point at which the expansion of cookie dough stops that is called the set time (Hosney et al., 1988). To calculate the set time of cookie dough, cookie dough (diameter 6.0 cm) was cut and placed in the baking oven maintained at 400° F. Corresponding cookie dough pieces were removed from the oven at one minute intervals until the finishing baking time.

Cookies were evaluated for height, diameter and texture. The following procedure was used to measure the cookie diameter. First, four cookies were placed next to each other to obtained the total diameter and then rotated to 90° to measure the new diameter. The average was taken from two measurements and divided by four to report the final value (Zoulias et al., 2002).

For the measurement of height, three cookies were selected randomly and placed one on top of the other to measure height. The average was taken to report the final value.

**Statistical Analysis**

Differences between the sugar and Splenda® cookies texture properties and baking quality characteristics were analyzed using one-way ANOVA. Comparisons were described as significant when $p < 0.05$.

# Chapter IV: Results

This chapter will describe the data collected from the texture analysis and breaking quality measurements.

## Texture Analysis of Cookies

The texture studies described in this work was measured using TA.XT2 texture analyzer. The hardness of cookie dough was measured and the breaking strength of cookie was measured.

**Compression force.** The force needed to compress the cookie dough from five altered samples are presented in Figure 11. The results showed that cookie dough containing 100% Splenda® required more strength to compress it and was the hardest. The results showed that hardness of cookie dough containing 25% Splenda® required least amount of force. ANOVA analysis showed that there is significant difference between the hardness of cookie dough containing 25%, 50%, 75% and 100% Splenda® when compare to control.

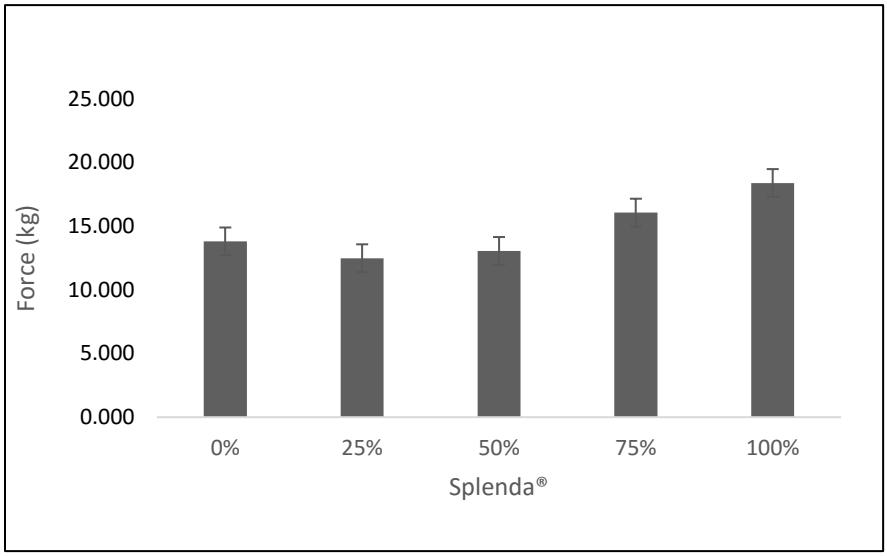


*Figure 11.* Effect on replacing sugar with Splenda® at (0%, 25%, 50%, 75% and 100%) on the hardness of cookie dough.

**Puncture test.** Breaking strength measurements showed that cookies containing 0% Splenda® were the hardest (Figure 12). All the cookies were significantly different from one

another. The breaking strength of cookies containing 25% Splenda® were the lowest and were very close to those containing 50% Splenda®. ANOVA showed that there is a significant difference between the breaking strength of cookies.

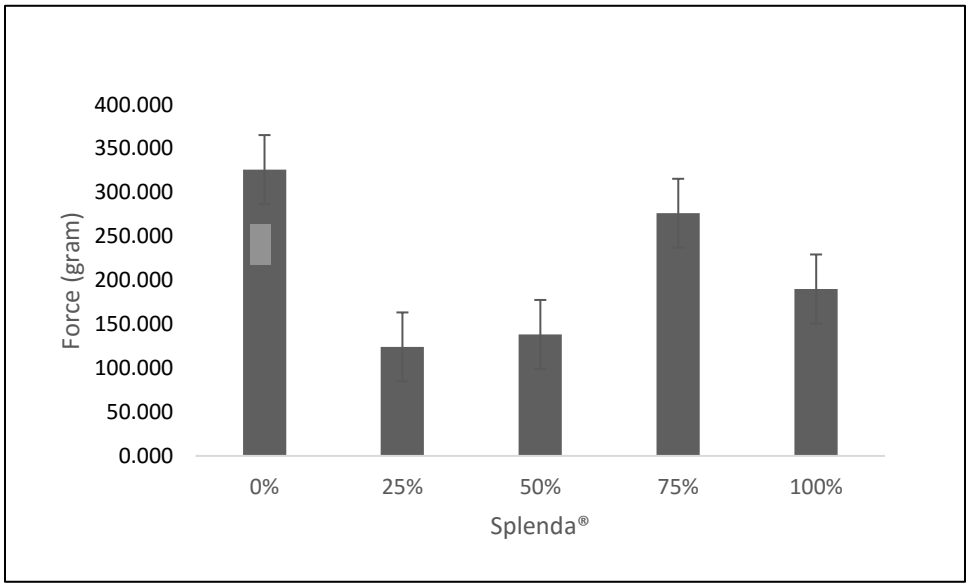


*Figure 12.* Effect on replacing sugar with Splenda® at (0%, 25%, 50%, 75% and 100%) on the cookie breaking strength.

**Baking Quality Measurement**

The results of cookie spread were shown in Figure 13. It was shown that the cookies containing 0%, 25% and 50% of Splenda® started to spread earlier than the cookie dough containing 75% and 100% Splenda® and constantly extended for a much longer time until the dough touched to its established point or set time.

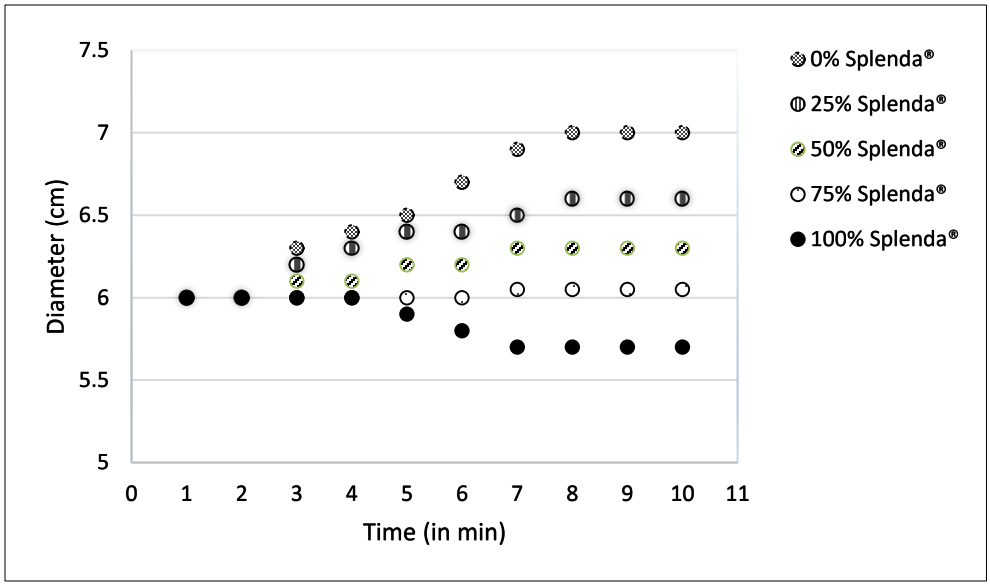


*Figure 13.* Effect on replacing sugar with Splenda® at (0%, 25%, 50%, 75% and 100%) on the cookie diameter.

Baked cookies diameter decreased from 0% to 100% Splenda®. An ANOVA showed that there was not significant difference on cookie diameter (Table 6).

Table 6

*Effect of Splenda® Supplemented for Sugar at Various Level on Cookie Diameter (cm)*

| Percent of Splenda® | Cookie Diameter |
|---|---|
| 0% Splenda® | 6.97 |
| 25%Splenda® | 6.57 |
| 50% Splenda® | 6.29 |
| 75%Splenda® | 6.05 |
| 100% Splenda® | 5.75 |

Cookie diameter was reduced from 6.97 cm for 0% Splenda® to 5.75 cm for 100% Splenda®. 40% sucrose did not dissolve in the dough before baking, the undissolved crystalline

part of sucrose dissolved into dough during baking, which is responsible for the increase in the diameter of the cookie.

An ANOVA showed a significant difference in cookie height (Table 7). Baked cookie height increased from 0% to 100% Splenda®.

Table 7

*Effect of Splenda® Supplemented for Sugar at Various Levels on Cookie Height (cm)*

| Percent Splenda® | Cookie Height |
|---|---|
| 0% Splenda® | 0.72 |
| 25% Splenda® | 0.78 |
| 50% Splenda® | 0.80 |
| 75% Splenda® | 0.83 |
| 100% Splenda® | 0.85 |

## Chapter V: Discussion, Conclusions and Recommendations

Cookie dough containing 25% Splenda® needed the least force to compress it and was the softest. It is also likely that dough containing only sugar or 25% Splenda® was more viscous and hence softer. There is significant difference between the compression force of cookie containing 25%, 50% and 75% Splenda® compared to control. The hardness of baked cookies comes from the gluten development. Since sugar competes with gluten for water, it results in soft cookies. When sugar is replaced with Splenda® at various levels, the increase in the amount of Splenda® results in less gluten development in the baked cookie. Dough containing 100% sugar spread much faster as compared to dough containing a different level of Splenda®. The initial diameter of all the cookie samples was 6.0 cm. Cookie dough containing 100% Splenda® did not expand at all and started to decrease in size after four minutes. The size of cookie dough containing 75% Splenda® did not increase significantly as compared to its actual size. Cookie dough containing 25% and 50% Splenda® increased compared to their actual size, although dough with 25% Splenda® spread faster and longer in comparison to dough containing 50% Splenda®. The cookies made with 100% Splenda® were the smallest in diameter due to the loss of sugar as Splenda® was increased. Replacement of sugar with Splenda® at different levels 25%, 50% and 75% does not reduced the diameter significantly ($p>0.05$). The height of cookies increased significantly ($p<0.05$) as the amount of sugar decreased.

### Conclusions

Results showed that the breaking strength, height of the baked cookie changed significantly when replaced sugar with Splenda® at the level of 25%, 50%, 75% and 100%. Results showed that before baking, there is significant difference between the compression force of cookie dough containing 25%, 50%, 75% and 100% Splenda®. Results shows that baked

cookie diameter does not have significant effect when replaced at levels of 25%, 50%, 75% and 100%.

**Recommendations**

Following future research are recommended based on this research:

1) Sensory analysis of baked cookies containing 25% Splenda®, 50% Splenda®, 75% Splenda® and 100% Splenda® and compare with control.
2) Effect of fat type on the baking quality characteristic and textural properties of cookies containing 25% Splenda®, 50% Splenda®, 75% Splenda® and 100% Splenda® and compare with control. Such fat can be, bakery fat, margarine, sunflower oil and hydrogenate fat.

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