EVALUATION OF THE BULK SWEETENER D-TAGATOSE AND

THE HIGH INTENSITY SWEETENER SPLENDA

AS SUGAR REPLACERS IN COOKIES

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EVALUATION OF THE BULK SWEETENER D-TAGATOSE AND THE HIGH INTENSITY SWEETENER SPLENDA AS SUGAR REPLACERS IN COOKIES

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VITA

Tanya Patrice Taylor, daughter of Franklin and Monica (Jarrett) Taylor, was born in Montego Bay, Jamaica. She attended Dunrobin Primary School and Campion College High School, before continuing on to higher education at The University of the West Indies (UWI) from which she graduated *with honors* with a Bachelor of Science degree in Chemistry & Food Chemistry. She pursued a further degree at Clemson University, Clemson SC, and graduated in May 2002, with a Master of Science degree in Animal and Food Industries, with a concentration in Food Chemistry. In August 2002, she entered Auburn University, to pursue a doctoral degree in Nutrition and Food Science.

DISSERTATION ABSTRACT

EVALUATION OF THE BULK SWEETENER D-TAGATOSE AND

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For a variety of health reasons, consumers are consuming more foods prepared with less metabolizeable sugars and artificial sweeteners. Before sugar replacers can be used in foods, their effect on food characteristics should be evaluated. This paper examines the effect of sucrose replacement by tagatose, Splenda and fructose in sugar cookies on both the rheological properties of cookie dough and physical properties of the cookies.

It was found that replacing sucrose with tagatose yielded cookie dough that was significantly harder and more chewy, but similar in adhesiveness, cohesiveness, resilience and springiness. Cookies made with tagatose had significantly greater height and lower diameter than cookies made with sucrose, resulting in a significantly lower spread ratio. Tagatose containing cookies were also harder and had a browner color than cookies made with sucrose and Splenda. Cookie dough and cookies made with Splenda had similar hardness values to cookies made with sucrose. Cookie dough made with Splenda had significantly higher values of springiness, and lower values for adhesiveness and cohesiveness than the sucrose-containing cookies. Cookies made with Splenda were similar in color and hardness to cookies made with sucrose, but showed the greatest height and smallest diameter, and consequently had a significantly lower spread ratio than cookies made with sucrose.

In a consumer acceptance test conducted with cookies baked with sucrose, tagatose, and a tagatose/sucrose mixture (1:1 w/w), the panelists best liked the sweetness of the cookies made with sucrose and the color of the cookies made with tagatose. The lowest overall acceptability was for cookies made with tagatose.

The data show that replacing sucrose with other sweeteners affects the properties and acceptability of cookies. To incorporate tagatose into cookies, blending it with sucrose gives more desirable results.

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CHAPTER 1

INTRODUCTION

In 2004, it was estimated that 180 million adult Americans were consumers of low calorie, sugar-free foods and beverages (CCC 2004). This increase in consumer demands have initiated a desire to lower the amount of metabolizeable sugars in food products, promoting a shift in consumer focus towards low and reduced calorie foods products containing sugar substitutes. From the perspective of consumers, the major concerns with these products are safety, the effect of sugar substitutes on organoleptic properties such as taste and flavor perception, and similarity of the textural properties, such as firmness and mouth feel, to traditional sugar-based products.

The discovery of novel reduced and non-caloric alternative sweeteners over the past decade has led to the development of various new sugar-free and reduced-sugar products. These sugar replacers can be broadly grouped into two categories, namely intense sweeteners and bulk sweeteners. Intense sweeteners, such as aspartame, acesulfame K and sucralose, are 180 - 800 times as sweet as sucrose, and therefore much less is needed to impart sweetness. The trade off, however, is that in commercially available products, loss of mass equates to a loss of bulk and body in the product, often necessitating the incorporation of bulking agents such as maltodextrins. Bulk sweeteners consist of modified monomers and dimers of common sugars, such as sugar alcohols. They have a sweetening effect similar to or lower than that of sucrose and possess a lower net caloric energy due to either poor digestability or absorption.

Alternative sweeteners can also be categorized as nutritive or nonnutritive, based on the provision of energy. Bulk sweeteners would be considered nutritive because they contribute calories, albeit to a lesser extent than sucrose. High intensity sweeteners would be considered non-nutritive because they do not provide any calories in the quantities used.

One sugar that has recently emerged as a potential replacer for sucrose is D-tagatose (commonly referred to simply as tagatose). Tagatose (Fig. 1.1a) is a stereoisomer of fructose (Fig. 1.1b), with an inversion of the hydroxyl and hydrogen group on the fourth carbon. It is found naturally in a number of products including powdered milk, cheeses and yogurt. It has 92% of the sweetening power of sucrose, but only contributes 1.5 kcal/g to the diet (Levin and others 1995), making it suitable for use as an alternative (bulk) sweetener. The manufacturer of D-tagatose (Biospherics, Beltsville, MD) states that the compound has no toxic, carcinogenic or teratogenic effects in tests conducted to date, under conditions specified by the Food and Drug Administration (FDA). This has facilitated it being granted GRAS (generally regarded as safe) status for use as a flavor enhancer in certain foods at specified concentrations. However, studies evaluating the effects of tagatose on food product quality are lacking.

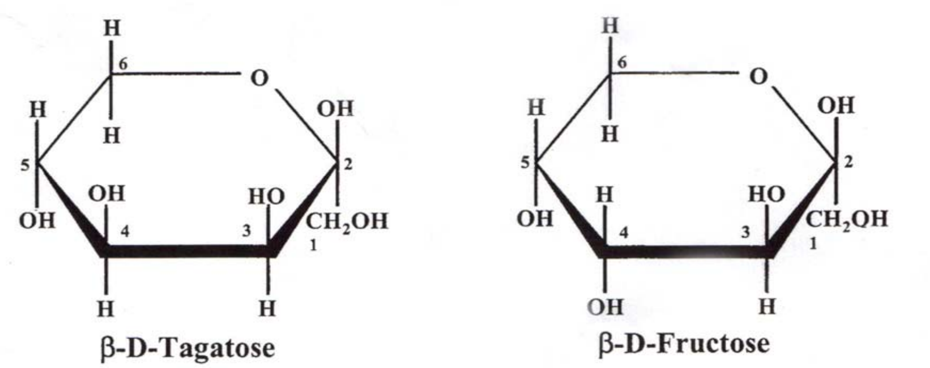


Figure 1.1: The pyranose structures of a) tagatose and b) fructose

Another sugar replacer recently introduced on the market is sucralose. Sucralose, 1, 6-dichloro-1,6-dideoxy-β-D-fructofuranosyl-4-chloro-4-deoxy-α-D-galactopyranoside, is a non-nutritive, high intensity alternative sweetener. It is 600 times sweeter than sucrose (Miller 1991), and is actually synthesized from sucrose by selectively chlorinating the primary hydroxyl groups and inversion of the configuration at carbon-4 from the gluco- to the galacto-analogue. Ingested sucralose is neither metabolized to its monosaccharide-like moieties, nor is it a source of energy. Since sucralose is so many times sweeter than sugar, it is combined with the bulking agent matlodextrin, and sold under the brand name Splenda. Sucralose was first approved for use in the USA in 1998 and was later granted approval for use as a table top sweetener in 1999 under the Splenda brand name (21CFR172.831). Like tagatose, the literature does not provide much information on the influence of Splenda on the properties of foods.

To date, there have been no published studies examining the effects of replacing sugar in baked products with the bulk sweetener tagatose or with the high intensity sweetener Splenda on the properties of the dough or baked product. Thus, the objective of this study was to evaluate the potential of D-tagatose and Splenda as a substitute for sugar (sucrose) in a baked product. Specific goals were:

1. To examine the effect of sugar replacement by tagatose and Splenda in sugar cookies on both the rheological properties of the dough and the physical properties of the finished product. The rheological properties to be examined include hardness, adhesiveness, cohesiveness, springiness, chewiness and resilience of the dough, and the physical properties of the cookies to be analyzed are the height, diameter, spread ratio, color and hardness.
2. To evaluate consumer acceptability of sugar cookies made with tagatose by conducting sensory evaluation.

CHAPTER 2

LITERATURE REVIEW

Sugar Related Definitions

Throughout history, sugar has been added to enhance the sweet taste of foods. Sugars help provide caloric energy, improve palatability, and mask unpleasant tastes. The ability to identify sweet tastes provides us with a sensory indicator to identify foods which may provide us with energy to fuel our metabolic needs. In common vernacular, *sugar* refers only to table sugar or sucrose. The United States Food and Drug Administration (FDA) has also adopted the stance that the term *sugar* indicates sucrose in ingredients statements and that the plural term *sugars* represent all mono- and disaccharides such as sucrose, fructose and glucose (21CFR101.4; 21CFR101.9). The United States Department of Agriculture (USDA) uses the term a*dded sugars* to refer to any sugar which can be eaten separately or used as ingredients in processed or prepared foods (USDA Dietary Guidelines for Americans 2005). Similarly, *caloric sweeteners* are defined by the USDA as nutritive sweeteners consumed directly and as food ingredients including oligosaccharides (Kantor and others 1997). The USDA definition therefore omits sugars naturally present in the food. In addition, in 2002, the FDA issued a regulation that prohibits the claim of 'no added sugar' for products containing any amount of sugars added during processing or packing or any other ingredient that contains sugars that functionally substitute for added sugars, such as jams, jelly and concentrated fruit juice (21CFR101.60). Table 2.1 lists the definitions and examples of particular sugars in each category.

Whereas there are many terms used to communicate information about sugars, chemical nomenclature is consistent and universal. Chemically, the term sugar refers to mono- and disaccharides. Monosaccharides contain 3-7 carbons in a single ring structure. The primary monosaccharides in the human diet (Figure 2.1) are glucose, fructose, and galactose (Groff and Gropper 2000). Disaccharides are two monosaccharide monomers joined together by a glycosidic linkage. They are most often found as individual sugars in foods, but can also be formed by enzymatic cleavage and degradation of polysaccharides. The primary disaccharides in the human diet (Figure 2.2) are sucrose, lactose, maltose, and isomaltose (Groff and Gropper 2000). Sucrose consists of α-glucose and β-fructose, lactose is β-galactose joined to α or β-glucose, maltose consists of an α-glucose unit joined to either α or β–glucose by a 1 to 4 α -glycosidic linkage, and isomaltose is two glucose units joined together by a 1 to 6 α-glycosidic linkage.

Table 2.1 Definition of commonly used sweetener-related terms and examples of nutritive sweeteners in each category.

Sweetener Term	Definition	Examples
Added sugars	Eaten separately or used as ingredients in processed or prepared foods	White sugar, brown sugar, raw sugar, corn syrup, corn syrup solids, high fructose corn syrup, malt syrup, maple syrup, pancake syrup, fructose sweetener, liquid fructose, honey, molasses, anhydrous dextrose, crystal dextrose. May include oligosaccharides.
Caloric sweeteners	Sweeteners consumed directly and as food ingredients	Sucrose, honey, dextrose, edible syrups, corn sweeteners (high fructose corn syrup). Also includes oligosaccharides.
Sugars	All mono- and disaccharides which includes those which naturally occur in the food or drink, or added	Sucrose, fructose, maltose, lactose, honey, syrup, corn syrup, high fructose corn syrup, molasses and fruit juice concentrate. Any oligosaccharides present are not included.
Sugar	Indicates sucrose in the ingredients statement	Primarily sucrose

(Sigman-Grant and Morita 2003)

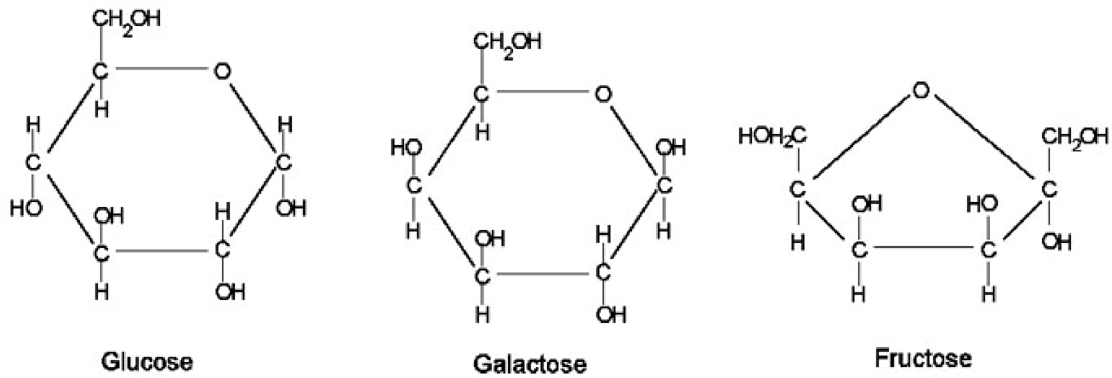


Figure 2.1 Chemical structure of the primary monosaccharides in the human diet.

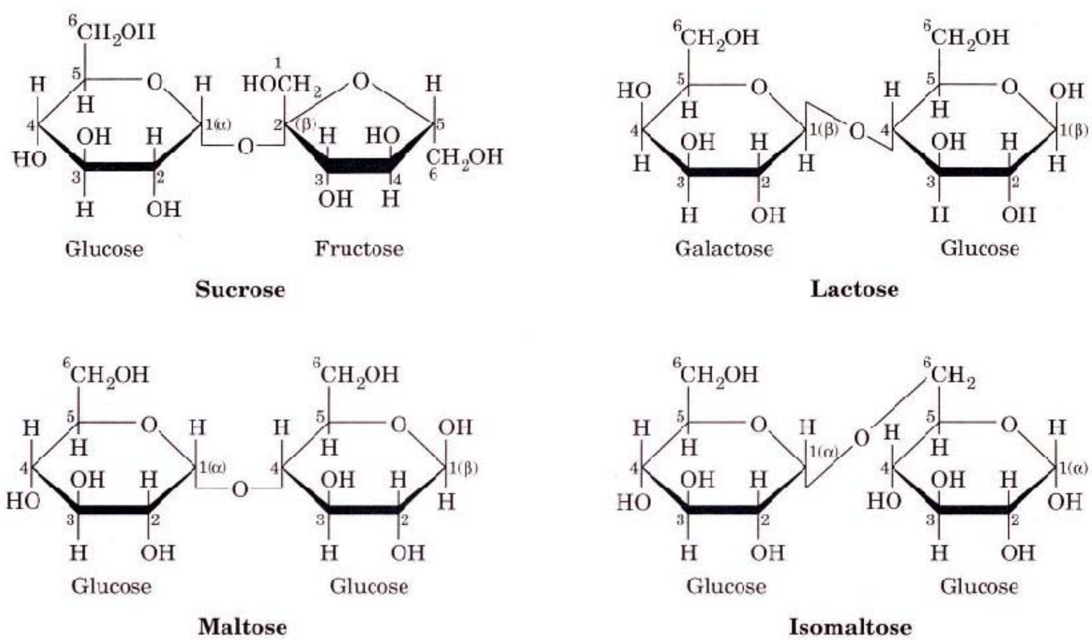


Figure 2.2 Chemical structures of the primary disaccharides in the human diet.

Sugars containing a free aldehyde group that can undergo oxidation to produce carboxylic acids are called reducing sugars. Examples of reducing sugars include the monosaccharides and the disaccharides lactose and maltose. Sucrose is not a reducing sugar. Because of the reactive carbonyl group, reducing sugars participate in the Maillard browning reaction with proteins. This reaction is one of the major factors involved in brown color formation of baked products. This will be discussed.

Sweet Taste Perception and the AH-B Theory

Taste is a complex perception, which is not yet fully understood. The sensations of sweet tastes are initiated by the interaction of compounds with G-protein coupled receptors (GPCR) located in the apical membranes of specialized epithelial cells known as taste receptor cells, found clustered in groups within taste buds. Through a transduction mechanism, the sweet chemical message is changed to a nerve signal for the perception of sweet taste (Margolskee 2001). The degree of sweetness depends on how well the receptors in our tongue interact with sweet tasting compounds. One model used to show these interactions is called the AH-B Theory, first presented by Schallenberger and Acree (1967). They described a mechanism by which the interaction between compounds and receptor sites in the taste buds elicit a sweet taste due to hydrogen bonding. They further suggested that the interaction was highly stereospecific and only the first in a series of dynamic chemical events that eventually resulted in the perception of sweetness (Schallenberger and Acree 1967).

The basis for this theory, as outlined by Acree (1970), is that all compounds which elicit the sweet taste response possess an 'active' portion. The active part of the molecule is believed to have an 'AH-B' configuration. 'A' refers to an electro-negative atom, such as oxygen or nitrogen, which has a proton (H) attached to it. The AH group acts as a hydrogen donor, or conversely, an electron acceptor. The AH group must be bonded in close proximity to an electron rich pi orbital system or electro-negative center, such as an oxygen or nitrogen (B). This electronegative center (B) accepts a hydrogen via hydrogen bonding. The receptor sites on the taste buds are also described as an AH-B system, and it acts as a receptacle for the AH-B system of the saporous unit of sweet compounds. The sweet taste response then is initiated by the formation of a pair of simultaneous hydrogen bonds between the receptor site and the saporous unit, diagrammatically shown in Figure 2.3.

The degree of interaction of the compound depends on its functional group, spatial arrangement, degree of polarity, distance in charge separation of the molecule, electron density, intermolecular hydrogen bonding and hydrophobic bonding (Schallenberger and Acree 1967). If these parameters match up with the receptor site, greater sweetness intensity is detected. The sweet taste receptor site contains three major features important for the perception of sweetness: a chemical environment in which the sweet compounds dissolve, topography which will accept only certain molecular shapes, and an electronic requirement which allows only certain electronic distributions within a saporous unit, i.e. an AH-B system. Schallenberger and Acree (1967) established that various sweet compounds such as saccharides, saccharin, and cyclamate contained the intramolecular AH-B system.

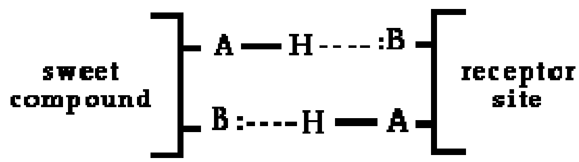


Figure 2.3 Diagramatic representation of binding between a receptor unit in taste buds with sweet tasting compounds (Acree 1970).

Schallenberger's hypothesis succeeded in rationalizing the mode of interaction of many types of sweet substances with the receptor. However, several independent studies suggested that there may be a third binding site in the molecule of a sweet substance as a prerequisite for the potent sweet taste response. This binding site was identified by Kier (1972) as X. Kier thus extended the original AH-B theory to AH-B-X, where X represents a lipophilic functional group (Figure 2.4).

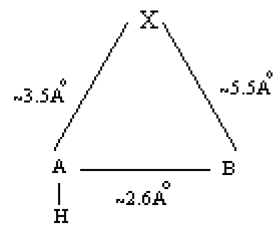


Figure 2.4 Diagramatic representation of the AH-B-X unit of sweet tasting compounds (Guley and Uhing 2000).

Sugar and Sweetener Related Food Labeling Regulations

The use of sweeteners is evaluated by governing bodies throughout the world. These include the FDA, expert scientific committees such as the Scientific Committee on Food (SCF) of the European commission (EC), the Joint Expert Committee of Food Additions (JECFA) of the United Nations Food and Agricultural Organization, and the World Health Organization (WHO). In the US, sweeteners are approved for use in foods either as generally recognized as safe (GRAS) or as food additives as defined by the 1958 Food Additives Amendment to the Federal Food, Drug and Cosmetics Act. GRAS sweeteners have scientific consensus on their safety based on a history of use or on well known scientific information (21 CFR, parts 182 and 184). Manufacturers often determine that use of a substance is GRAS and notifies the FDA of their conclusions. Substances whose use is GRAS are not subject to FDA approval. Manufacturers may market on the basis of their own determination, provided that such a determination is correct. On the other hand, food additives must be approved by the FDA.

Replacing or reducing sugars in foods will affect the caloric content and hence the energy value of the food. The FDA has specific guidelines related to reduced-calorie and sugar-related claims allowed on food labels. Foods which have been made to reduce calories can be labeled calorie free, low calorie, reduced calorie, or light. The definitions of these terms are specified in the FDA Code of Federal Regulations (21CFR101.60). A food can be labeled *calorie free* if it contains less than 5 calories per serving or per 50 g if the serving size is small. The term *low calorie* can be used if the food has 40 cal or less per serving or per 50 g if the serving size is small. Foods can be labeled *reduced calorie* if they contain at least 25% fewer calories per serving than an appropriate reference food. *Light* or *lite* can be used on labels if the fat content is reduced by at least 50% per reference amount when 50% or more of the calories in the food is from fat, or calories are reduced by at least 1/3 per reference amount if the food contains less than 50% of calories from fat (21CFR101.60).

Foods that have reduced the amount of sugars than would otherwise be present can be labeled reduced-sugar, sugar-free, or no-added-sugar. A food can be labeled *sugar-free* if it contains less than 0.5 g sugars per reference amount and per labeled serving. It can be labeled *reduced sugar* if the sugar content has been reduced by at least 25% per serving as compared to an appropriate reference food. The term '*no added sugars*' is used if no sugar or sugar-containing ingredient is added during processing.

Traditional Natural Sweeteners

Sucrose and fructose are the primary natural sweeteners that are present in and added to foods. They both provide 4 kcal/g of energy and are thus termed nutritive or caloric sweeteners. Both have GRAS status as approved by the FDA. Sucrose occurs naturally as a component of the carbohydrate of every fruit and vegetable in the plant kingdom (Coulston and Johnson 2002). Sucrose cannot be cost effectively synthesized for use as an added food ingredient, or extracted from most plants. As a result, sucrose is commercially produced from processing sugar cane or sugar beets. A stalk of sugar cane plant contains 12-14% sucrose and sugar beets contain 16-18% sucrose. Sucrose is extracted from these plants through a process of water extraction, clarification, filtration, concentration, crystallization, and drying. Refinement removes the yellow-brown pigments of unrefined sugar to produce the white crystal form known as granulated or table sugar (The Sugar Association 2005). Molasses is a brown viscous liquid byproduct that results as well. Sucrose is primarily used in bakery and cereal products, candy and confectionary items, ice cream and dairy products, beverages, and canned, bottled and frozen foods.

Fructose, also known as fruit sugar or levulose, is found mainly in fruits. It is added to foods and beverages in a crystalline form and as high fructose corn syrup (HFCS). Fructose has a slightly higher sweetness level than sucrose (Table 2.2). Corn refiners produce HFCS by first converting cornstarch to syrup that is nearly all glucose. Enzymes isomerize the glucose to produce a syrup that contains 42% fructose, known as HFCS-42. By passing this 42% syrup through an ion-exchange column that retains fructose, corn refiners are able to draw off 90% HFCS and blend it with the 42% HFCS to make a syrup that has 55% fructose, known as HFCS-55 (Bhosale and others 1996). Use of HFCS has seen a dramatic increase in the past decade. Domestic production of HFCS increased from 2.18 million tons in 1980 to 9.4 million tons in 1999 (Elliot and others 2002). They estimated that by 1985, HFCS accounted for approximately 35% of the total amount of sweeteners in the U.S. food supply. They attributed this increase to the lower cost of HFCS compared to raw sugar. From 1985 to 1999, the annual U.S. raw sugar price averaged 22 cents per pound and fell to slightly below 18 cents per pound in 2000. In 1994, price of HFCS averaged close to 19 cents per pound, but has averaged slightly more than 11 cents per pound for most of 2000 (Economic Research Service, USDA 2002). HFCS is used in beverages, processed foods, cereal and bakery products, dairy products, candy and other confectionary products (Sigman-Grant and Morita 2003). Glucose, maltose, honey and other edible syrups, such as maple syrup, are also used but to a much less extent than sucrose and HFCS.

Table 2.2 Relative sweetness of sugars.

Food Ingredient	Relative sweetness (by weight, solids)
Fructose	1.3
High Fructose Corn Syrup (55% fructose)	1.1
High Fructose Corn Syrup (42% fructose)	1.0
Sucrose	1.0
Glucose	0.7
Lactose	0.2

(Coulston and Johnson 2002)

Functionality of Sugars in Foods

Texture, along with appearance and flavor, are the three major criteria which consumers use to judge the quality foods. The incorporation of sugars into foods influences all three characteristics. Additionally, the properties of sugars affect sensory characteristics, physical structure, microbial safety and chemical development (Table 2.3). Two of the most important contributions of sugars in baking is due to their hydration properties and participation in browning reactions.

Table 2.3 Influence of sugar on food properties.

Food Characteristic	Sugar Property
Sensory	Sweetness
	Taste and aroma
	Texture
	Appearance and color
Physical	Crystallization
	Viscosity
	Osmotic pressure
	Hygroscopicity
	Consistency
	Grain size and distribution
Microbial	Preservation
	Fermentation
Chemical	Non-enzymatic browning
	Carmelization
	Antioxidant

(Davis 1995)

Sugar and water function

The chemical and structural composition of sugars is one of the most important contributing factors to their ability to have numerous functions in foods. Traditional sugars have hydroxyl groups in their structure. This makes them hydrophilic because these groups will interact readily with water molecules by hydrogen bonding, which leads to solvation, and solubilization of sugars and many of their polymers. This hydrophilic property influences the degree of solubility of sugars, the viscosity of food systems, and the ability of sugars to attract water in food systems, sometimes preferentially over other ingredients. For example, the hydration properties of sugars restrict starch and protein hydration and therefore limit starch gelatinization and protein denaturation.

Differences in solubility and water affinity between sugars are mainly due to differences in configuration and conformation. The solubility of some traditional sugars is shown in Table 2.4. Lactose, for example, is one of the less soluble sugars. At room temperature, lactose is approximately one-tenth as soluble as sucrose (Kulp and others 1991). The ability of a sugar to absorb water from the atmosphere is referred to as hygroscopicity, whereas the ability to attract water in a food is referred to as humectancy. Humectancy properties of sugars can affect which ones are used in a product. For example, in bakery products with icings, an unwanted complication would be for the icings to become sticky after packaging. Therefore, use of sugars with a limited absorption capacity is preferred. Lactose absorbs more water than sucrose at 60% relative humidity (Kulp and others 1991), therefore it can function as a better anticaking agent, an effect that contributes to its stabilizing influence in coating sugars.

In other situations, avoidance of water loss may be important; therefore it may be necessary to use more hygroscopic sugars such as high fructose corn syrup, which are particularly useful in helping to retain moisture in baked goods.

Table 2.4 Solubility of traditional sugars at 20°C

Sugar Type	Solubility (g solid/100g H_2O)
Sucrose	199.4
Dextrose	478.0
Fructose	789.4
Lactose	18.3

(Kulp and others 1991)

Browning reactions of sugars

Sugars participate in two types of browning, caramelization and Maillard browning. Direct heating of sugars produces a complex group of reactions termed 'caramelization.' Thermolysis first results in melting of the sugars, and eventually dehydration which can lead to formation of anhydro rings or introduction of double bonds into the sugar structures, which can lead to furans (Kamuf and others 2003). The temperature must be higher than the melting point of the sugars, and catalysts, such as small amounts of acids and certain salts, speed up the reactions, and can be used to direct the reaction to specific types of caramel colors. In unsaturated ring systems, condensation will occur to polymerize ring systems, yielding color and flavor compounds. Sucrose is often manipulated to produce caramel colors and flavors for many industries. It is heated in solution with the ammonium bisulfite catalyst to produce the caramel color of colas. A brewers color for beer is made by heating a sucrose solution with ammonium ion, and a burnt sugar color produced by direct pyrolysis of sucrose is utilized in the baking industry.

Maillard browning, also known as nonenzymatic browning, is a complex series of reactions, which starts with a condensation of a free amino group and a reducing sugar, and ends with the formation of brown pigments. The reaction progresses via the condensation reaction of the carbonyl group of the carbohydrate with the amino group of the protein leading to formation of a glycosylamine. The glycosylamine undergoes rearrangement to produce a 1-amino-2-keto sugar, eventually leading to the formation of brown melanoidin pigments (Ashoor and Zent 1984). At the onset of the reaction, the compounds are colorless, but as the reaction progresses, the compounds produced are increasingly more pigmented and a caramel-like aroma develops. Maillard browning has effects on flavor, color, and texture of food materials, in addition to affecting the nutritional quality via loss of protein functionality (Friedman 1996). The Maillard reaction is involved in producing the brown colors of baked products, and gives bread crusts that characteristic dark brown color, but this brown color is not always desired, as is the case in the production of nonfat dry milk and dried egg products.

The extent of the Maillard reaction must be controlled in circumstances where it is desired, and minimized or prevented when it is not. This can be accomplished by manipulating the pH because little or no Maillard browning occurs at a pH of less than 6 (Friedman 1996). The type of sugar used in food applications is also important in controlling Maillard browning. The reaction only occurs with reducing sugars; therefore use of a non-reducing sugar will prevent the reaction from occurring. The extent to which the type of sugar contributed to Maillard browning was first noted by Maillard (1912). He found that that D-xylose showed greater browning than L-arabinose, followed by the hexoses (D- galactose, mannose, glucose and fructose), and followed by the dissacharides maltose, lactose and sucrose. Removing one of the substrates, either the sugar or the protein, will also prevent the reaction. Unwanted browning is a common problem in dehydrated eggs due to the presence of lysine and glucose in eggs, which will react together in the event of a thermal treatment such as dehydration. This can be prevented by addition of D-glucose oxidase prior to drying as this degrades the reactant D-glucose. A chemical method used to inhibit browning is addition of sulfites, which prevent the formation of melanoidin pigments.

Fermentation

Monosaccharides (or the formation of monosaccharides from the hydrolysis of disaccharides and polysaccharides) can be used as a fermentation substrate. For example, yeast ferments sugars into alcohol and carbon dioxide. This is utilized in the baking of breads where the production of carbon dioxide results in a leavening action during baking. The carbon dioxide stretches gluten to facilitate its development and causes the dough to rise, thereby contributing to its texture (Davis 1995). In making of breads, yeast slowly ferments carbohydrates present in flour. Added sugars are fermented more rapidly by yeasts, and do not contribute to giving the bread a sweet taste since they are partly consumed. Fermentation of sugars by yeasts is also utilized in the production of alcoholic beverages.

<u>Alternative Sweeteners</u>

Increase in global obesity rates (Kuczmarski and others 1994; Grundy 1998; Ebbeling and others 2002) has prompted greater consumer awareness of dietary factors that cause energy intake to exceed energy expenditure (Murphy and Johnson 2003). Up to 9 in 10 consumers in the United States buy or use low-calorie products, including sugar-free and reduced-fat foods and in European countries, use of nonnutritive sweeteners has also seen an increase due to the growing interest in health and an aging population (Bright 1999). Thus, scientists have responded to consumer demand by researching, developing and producing a number of alternative reduced-calorie and nonnutritive sweeteners.

Reduced-calorie sweeteners

Reduced-calorie sweeteners, such as sugar alcohols and stereo-isomers of traditional sweeteners, provide a sweet taste and a source of energy or calories, which are fewer than that of traditional sweeteners. Because they contribute some calories to the diet, they are also classified as nutritive sweeteners. Examples of these are sugar alcohols, also known as polyols, trehalose and tagatose. Tagatose is one of the most newly approved nutritive sweeteners. Each of these sweeteners tend to have similar properties to sucrose, but are less sweet.

Polyols

Polyols, or sugar alcohols, are chemically defined as saccharide derivatives in which a carbonyl group (C=O) is replaced by a hydroxyl (-OH) group. Thus polyols are not sugars, and are named with the suffix –itol instead of -ose. Members of this group include sorbitol, mannitol, maltitol, lactitol, isomalt, xylitol, and erythritol. Polyols have fewer calories per unit mass compared to sucrose (Ziesenitz and Siebert 1987) but actual permitted calorie claims differ according to region-specific food legislation. For food labeling purposes, the European Union (EU) has agreed that in calculating the energy value of food, the caloric value of all polyols shall be 2.4 kcal/g compared to a value of 4 kcal/g for sugars. In the USA, energy values differ depending on the particular polyol. Mannitol has been assigned the lowest value of 1.6 kcal/g, while isomalt and lactitol provide 2 kcal/g. Xylitol provides 2.4 kcal/g, sorbitol 2.6 kcal/g and maltitol provides 3 kcal/g (Zumbe 2001).

All polyols have a pleasant, clean and neutral taste in solution, the extent of which varies according to the individual polyol. The body, mouthfeel and taste profiles can be compared with those of sucrose. As with sucrose, most polyols also exhibit hygroscopic properties, which again vary according to the polyol. In addition, some polyols have a characteristic cooling effect, which is due to the negative heat of solution which they exhibit. This gives a cooling sensation in the mouth when products with polyols are ingested. Of the polyols, xylitol exhibits the greatest cooling effect, and so is used in mints and some chewing gums.

Polyols are non-cariogenic, because they resist fermentation and acidogenesis by the microorganisms responsible for dental plaque, such as *Streptococcus mutans* (Kandleman 1997). They are not absorbed by the stomach to any significant degree. Some di-, oligo- and polysaccharides may liberate glucose, but as their digestion is slow and incomplete, there is not a substantial rise in blood glucose levels (Nguyen and others 1993). This means that polyols have little influence on glycemic response and have low energy values (Livesey 2003). Unabsorbed polyols are generally fermented completely by colonic microflora. The polyol lactitol has been acknowledged for its ability to reduce circulating levels of NH_3 and toxic microbial substances, the clinical utility of which is the treatment of hepatic encephalopathy (Blanc and others 1992).

Laxative action has been observed for acceptable intakes of xylitol, sorbitol, manitol, isomalt, lactitol, maltitol and erythritol (Livesey 2001; Marteau and Flourie 2001). Laxation is defined as the 'gentle stimulation of the bowel to render the motion slightly soft without causing any gripes' (Macpherson 1990). Over-consumption of polyols may cause a variety of intestinal symptoms including increased bowel movement frequency, diarrhea, colic, bloating, flatulence and borborygmi (Zumbe and others 2001). There are also differences between the polyol in terms of tolerance. For example, the disaccharide alcohol isomalt is better tolerated than the monosaccharide alcohol sorbitol, which exerts a greater osmotic load in the intestine (Zumbe and Brinksworth 1992; Lee and others 1994).

Within the EU, foodstuffs containing more than 10% of added polyols are required to bear the warning label 'excessive consumption may produce a laxative effect' (EC 1994). In the USA, the requirement of a warning on the label depends on the type of polyol. The label 'excessive consumption may have a laxative effect' is mandatory on a case-by-case basis. For example, products containing sorbitol and manitol require the warning, but for products with lactitol, maltitol and isomalt, no statement is required.

Polyols can be used in any sugar free and reduced calorie food products. As previously mentioned, polyols can be used to replace the bulk lost by eliminating sugar in 'sugar-free' products. They have also found a niche use in confectionery, such as sugar-free mints, chewing gum, hard-boiled candy, gelatin gums and chocolate. Their extensive use in these products is due to the desired cooling effect characteristic, and/or the fact that the small quantities used will not result in gastric upset, and require no warning labels.

Trehalose

Trehalose is a disaccharide that occurs naturally in insects, plants, fungi, and bacteria. Its structure (Figure 2.2) is similar to that of maltose in that it is comprised of two glucose units, but they are linked by an α,α-1,1 linkage. Like sucrose, trehalose contributes 4 kcal/g, but is only half as sweet as sucrose (Komes and others 2005). Natural food sources of trehalose include honey (0.1–1.9%), mirin (1.3-2.2%), brewer's (0.01-5.0%) and baker's yeasts (15-20%), and therefore most items made using yeast, as well as in invertebrates such as lobster (2.5 mg/100 ml blood) and prawns (0.5% dry weight) (Murray and others 2000, Van Dijck and others 1995). Trehalose is noted for having a protective function in some animals. This effect was first noticed in a group of desert animals called cryptoboints, which can survive during long periods of drought. Young (1985) reported that certain cryptoboints, such as bacteria, yeast, and fungi, contain 20% of their dry weight as trehalose, and it seems to be responsible for their ability to go through cycles of dessication and rehydration without injury.

Trehalose was first approved as a novel food in 1991 in the UK for use as a cryoprotectant for freeze-dried foods at concentrations up to 5%. In 1995, trehalose was granted approval for use as a food additive in Japan, with no limits to its use. Similarly, in 1998, trehalose was approved as a food ingredient in Korea and Taiwan. Trehalose was granted GRAS status in the United States in 2000, and regulatory approval was granted for use throughout Europe in 2001 (Richards and others 2002).

The metabolism of trehalose is similar to that of other disaccharides. Ingested trehalose is hydrolyzed to glucose and absorbed in the small intestine.

Trehalose has been shown to elicit a very low insulin response and provide sustained energy (Richards and others 2002). In addition, trehalose protects and preserves cell structure in foods and may aid in the freezing and thawing process of many food products by assisting in the maintenance of the desired texture of the food. It is also heat stable. Because trehalose is only half a sweet as sucrose, it is more likely to be used for cell preservation than for sweetness. Trehalose may be used in beverages, including fruit juices, purees and fillings, nutrition bars, surimi, dehydrated fruits and vegetables, and white chocolate for cookies or chips.

D-Tagatose

D-Tagatose is a monosaccharide sugar present naturally in minute amounts in some dairy products (Table 2.5). Commercially, it is manufactured by enzymatic hydrolysis of food grade lactose using immobilized *Aspergillus oryzae* to form D-galactose. D-galactose then undergoes a chemical isomerization reaction induced by calcium hydroxide to form D-tagatose, which is purified by mineralization, ion exchange chromatography, and recrystallization (FDA/CFSAN 2001). Tagatose has 92% the sweetening power of sucrose, with a similar sweetness profile, but a faster onset like fructose. Tagatose is 58% (wt/wt) soluble in water at 21°C (Levin 2002).

Tagatose has a number of beneficial properties over traditional sweeteners including a low caloric value, does not promote tooth decay, minimal increase in blood sugar and probiotic effects, as detailed in subsequent sections. Tagatose has been granted GRAS status for food use in limited quantities in the United States (Table 2.6).

Net caloric energy & metabolism of tagatose

Livesey and Brown (1996) conducted a randomized parallel design study in rats to determine the net metabolizable energy value (NEV) derived from D-tagatose. NEV was defined as the energy available to the rats from the supplement after accounting for all supplement induced energy losses, such as losses to feces, urine, combustible gases, and supplement-induced energy expenditure. Rats consumed 1.8 g D-tagatose daily as a supplement to a basal diet for 40 – 41 days. Growth, protein and lipid deposition were found to be unaffected by energy intake from D-tagatose. They determined that NEV was -3 ± 14% and therefore effectively has a zero energy value. Further mathematical calculations using a factorial model for the estimation of the physiological caloric value reported a range from 1.1 to 1.4 kcal/g for the net energy from tagatose (Levin 2002). As a result of these studies, a conservative caloric estimate of 1.5 kcal/g for tagatose was submitted and approved by the FDA.

Table 2.5 Natural occurrence of D-tagatose in foods

Food	Concentration (mg/kg)
Sterilized cow's milk	2 - 3000
Hot cocoa	140 - 1000
Powdered cow's milk	800
Similac infant formula	4
Enfamil infant formula	23
Parmesan cheese	10
Gjetost cheese	15
Cheddar cheese	2
Roquefort cheese	20
Feta cheese	17
Ultra-high temperature milk	5
BA Nature yogurt	29

(Levin 2002)

Table 2.6 GRAS food categories for tagatose and allowed level of use

Food category	Functionality	Allowed Level of use (g/100g)
Baked goods	Flavor enhancement	2
Beverages	Flavor enhancement	1
Frozen milk- based desserts, reduced/ low fat	Bulk sweetener, texturizer	3
Hard candies	Bulk sweetener, texturizer	15
Health bars and diet soft candies	Bulk sweetener, texturizer	10
Icings	Bulk sweetener, texturizer	30
Meal replacement beverages	Bulk sweetener, texturizer	5 g per serving (240 ml)
Protein drinks, supplements and diet beverages	Bulk sweetener, texturizer	1
Milk chocolate	Flavor enhancement	3
Ready-to-eat cereals	Bulk sweetener	3 g per serving
Smoothies	Flavor enhancement	1
Soft chewy candies	Flavor enhancement and bulk sweetener	3
Sugarless chewing gum	Bulk sweetener	30
Table top sweeteners, low calorie	Bulk sweetener	1 g per serving
Yogurt	Flavor enhancement	2

(Gaio Tagatose 2005)

Laerke and Jensen (1999) looked at the digestability of D-tagatose in pigs. Pigs were fed a low fiber diet comprising either 15% sucrose or tagatose. After 18 days, the pigs were killed and the digestability of tagatose was found to be 25.8 ± 5.6% in the distal third of the small intestine, considered to be maximum digestability. The results suggested that the ingested tagatose is almost completely fermented in the cecum and proximal colon. Similarly, rats given radio-labeled tagatose metabolized only 15% to 20% of the tagatose they absorbed in the small intestine (Saunders and others 1999). Rats with normal levels of gut microflora excreted 93% less tagatose in their feces than did germ-free rats, indicating that most of the tagatose ingested is not absorbed through the small intestine but passes to the lower gut, where it is fermented by bacteria.

Safety and effects of D-tagatose in humans

Numerous animal studies have been done on the toxicity effects of tagatose in preparation for submission to the FDA for approval for food use. No toxic effects were found (Kruger and others 1999a, 1999b, 1999c). Donner and others (1999) examined the acute glycemic effects of oral D-tagatose in human subjects with and without type 2 diabetes mellitus. The initial study was conducted using two groups of 8 participants each, with one group of participants having diabetes mellitus. They found that oral loading with D-tagatose did not lead to changes in glucose or insulin levels in either normal patients or patients with diabetes mellitus. A second part of the study was conducted to examine the adverse effects of consumption of dosages of D-tagatose. At dosages of up to 20 g, only 1 in 10 subjects reported any symptom, and this was usually nausea. At a dosage of 30 g, 1 subject reported nausea and one other reported bloating. At the highest dosage given, 75g, each subject (n=16) reported some gastrointestinal side effect with symptoms including diarrhea, nausea, flatulence, bloating, abdominal pain and headache. Diarrhea was the most common symptom, experienced in 13 of the 16 subjects.

This result was similar to results from a study reported by Lee and Story (1999) that looked at comparative gastrointestinal tolerance of sucrose, lactitol and D-tagatose in chocolate. In the double blind, controlled, crossover study, 50 healthy adults' ages 18 – 24 years were given 2 x 20 g plain chocolate bars containing 20 g of sucrose, lactitol or D-tagatose. Half the study group consumed lactitol-containing chocolate on day 1 of the study, the sucrose-containing chocolate on day 9, and tagatose-containing chocolate on day 17. The other group consumed tagatose-containing chocolate on day 1 of the study, the sucrose-containing chocolate on day 9, and lactitol-containing chocolate on day 17. The subjects were then debriefed using questionnaires 24 hours after product consumption. The researchers looked at borborygmi (intestinal rumbling caused by moving gas), colic, bloating, flatulence, thirst, loss of appetite, nausea, and number of toilet visits to pass watery or hard feces. They found that consumption of D-tagatose was not associated with a significant increase in the frequency of passing feces, or in the number of subjects passing watery feces when compared to the control (sucrose), whereas there was a significant difference after consumption of lactitol-containing chocolates. Consumption of chocolates containing lactitol and those containing D-tagatose did result in a significant increase in colic, flatulence, borborygmi, and bloating as compared to the sucrose-containing chocolate, but the majority of symptoms were described by the participants as only slightly more than usual.

Prebiotic Properties of D-tagatose

Prebiotics are nondigestable substances in food that have a beneficial effect on the host by selectively stimulating the growth or activity of colonic bacteria leading to an improvement of host health. Bertelsen and others (1999) conducted animal studies and a human trial. In the studies with pigs, they found a dose response increase in the short chain fatty acid (SCFA) butyrate to the amount of tagatose ingested. Human *in vitro* studies showed similar results. This increase in butyrate indicates the selection of butyrate-producing bacteria in the colon. Butyrate is important in the colon because it has been shown to be one of the major fuels for colonic epithelial cells, and arrests the growth of tumor promoting bacteria (Johnson 1995). Thus, the consumption of tagatose leads to changes in the SCFA distribution within the intestines that promote intestinal health.

Non-nutritive sweeteners

Non-nutritive sweeteners (which are also classified as artificial and high intensity sweeteners) are synthetic and do not contribute any caloric energy to humans. They provide sweetness without the calories and can therefore assist in weight management. Furthermore, they assist in control of some health problems such as diabetes and hypoglycemia, and help prevent formation of dental caries (Sandrou and Arvanitoyannis, 2000). However, use of nonnutritive sweeteners in product formulations is not without challenges. They usually cannot replace sucrose completely in a majority of foods because they lack some of the functional properties of sugar such as bulk, humectancy, water binding and plasticizing (Alonso and Setser 1994). The FDA has approved five high intensity sweeteners: aspartame, acesulfame K, saccharin, sucralose and neotame (Table 2.7).

Table 2.7 Relative sweetness of high intensity sweeteners to sucrose

Sweetener	kcal/g	Brand Names	Relative Sweetness
Saccharin	0	Sweet and Low, Sweet Twin, Sweet 'N Low Brown, Necta Sweet	300 - 500
Aspartame	4	Nutrasweet, Equal, Sugar Twin	160 - 220
Acesulfame-K	0	Sunnett, Sweet & Safe, Sweet One	200
Sucralose	0	Splenda	600
Neotame	0	none	8000

(ADA Reports 2004)

Saccharin

Saccharin (Fig. 2.5) is the oldest approved high intensity sweetener. It was discovered in 1879 by Remsen and Fahlberg (Weihrauch and Diehl 2004). It has been used commercially to sweeten foods and beverages since the turn of the century. It is 300-500 times sweeter than sucrose. Saccharin was first sold in the U.S. from the late 1890s to the 1940s in tablet form. It was introduced in granulated form as the tabletop sweetener Sweet 'N Low in 1957.

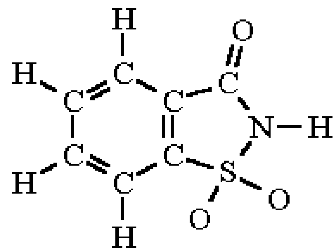


Figure 2.5 Chemical structure of saccharin

In 1958, Congress passed the Food Additives Amendment to the Food, Drug, and Cosmetic Act, which required pre-market approval from FDA for food additives developed after 1958. This requirement did not apply to ingredients with GRAS status, such as saccharin, so it remained on the market. Although saccharin is not metabolized when ingested, a Canadian study reported an increased incidence of bladder cancer in lab rats exposed to high doses of saccharin for at least 1.5 years (Fukushima and others 1983). This was only one of 20 study groups that analyzed the effect of saccharin in one generation of rats (Weihrauch and Diehl 2004). None of the other studies found significantly more cancer in the saccharin-fed animals than in controls. The FDA however, proposed a ban on saccharin in 1977.

Following the 'one generation' studies, 'two generation' studies were conducted feeding the parent and the following generation with saccharin. In these studies, an increased risk for bladder cancer was consistently proven for the offspring (Taylor and others 1980). This resulted in prohibition of saccharin in Canada. In further studies with monkeys (Takayama and others 1998) and in longitudinal and case-controlled studies in humans (Weihrauch and Diehl 2004), no elevated risk of cancer has been shown. The proposed ban was formally withdrawn in 1991 in the USA. The National Institute for Environmental Health Sciences removed saccharin as a possible cancer causing agent from its reports because it could be shown that the cancer-inducing mechanisms in rats do not apply to humans. The FDA still required a warning label on products containing saccharin, but this requirement was removed in 2000, after the FDA gave saccharin a clean bill of health.

The FDA has approved saccharin as a sweetener in beverages in amounts not to exceed 12 mg/fl oz, as a sugar substitute packaged in amounts not to exceed the sweetening power of 1 teaspoon of sugar (20 mg) for retail use, and not more than 30 mg per serving when used in processed foods; the label of such products must state saccharin in the ingredient declaration (21CFR180.37).

Saccharin is highly stable under food manufacturing conditions, making it suitable for cooking and baking. It does not promote tooth decay and is synergistic when combined with other low calorie sweeteners (Sandrou and Arvanitoyannis 2000). Because it has a good shelf life, saccharin is used widely in fountain sodas, and its stability at high temperatures makes it an option for sweetening baked goods, unlike aspartame, which degrades when heated.

Blends of saccharin and other high intensity sweeteners display the property of synergism where the net sweetness of the blend exceeds the additive sweetness of the individual sweeteners. In addition to being synergistic with other high intensity sweeteners, it can also be made more inexpensively than sucrose (Wells 1989). One disadvantage of saccharin is that it has a slightly bitter taste in aqueous solutions (Walter and Mitchell 1986). For that reason, saccharin is used in combination with other high intensity sweeteners to lower the amount used and reduce the bitter aftertaste.

Aspartame

Aspartame, N-aspartyl-L-phenylalanine-1-methyl ester, is a dipeptide of two amino acids, L-phenylalanine and L-aspartic acid (Figure 2.6). The sweet taste of the compound was first discovered in 1965 by Searle & Co. It has the same caloric value as sugar (4 kcal/g), but is about 200 times sweeter than sugar and so only a small amount is needed to sweeten products. The taste of aspartame is almost indistinguishable from that of sucrose, and it intensifies and enhances other flavors present (Homler 1988). It was first approved for use in the United States by the FDA in 1981 as a tabletop sweetener under the trade name "Nutrasweet" and for use in various foods and dry beverage mixes (21CFR 172.804). In 1983, the FDA approved aspartame for use in carbonated beverages, and set the ADI to 50 mg/kg body weight/day. It was later approved for general use in foods and beverages in 1996.

Upon digestion, intestinal esterases hydrolyze aspartame to produce phenylalanine, aspartic acid and methanol, which are then absorbed in the blood (Ranny and others 1976). Certain individuals have a genetic disorder called phenylketonuria (PKU), which is characterized by an inability of the body to utilize phenylalanine. This causes a buildup of phenylalanine in the blood and body tissues, which can lead to brain damage. Thus, the FDA requires products that contain aspartame to bear the warning label, 'Phenylketonurics: contains phenylalanine.'

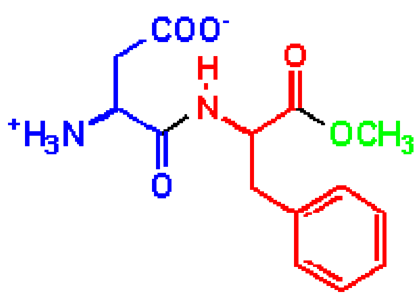


Figure 2.6 Chemical structure of aspartame

Animal studies showed that aspartame does not have any cancer-inducing effects, even in very high doses (Ishii 1981). However, in 1996, there was an article published theorizing a link between increasing brain tumor rates since

1980 and the introduction of aspartame (Olney and others 1996). This article was widely cited in the media, but was criticized strongly in the scientific community because the authors linked two events that incidentally occurred at the same time, but didn't show a causative relationship, or even that the people who developed brain cancer had ever consumed aspartame. In fact, in a case-control study conducted on children with brain tumors (Gurney and others 1997), no elevated brain tumor risk was found to the child from maternal consumption of aspartame during pregnancy or during breast-feeding.

Aspartame is stable in solid form when not exposed to excessive moisture (Wang and Schroeder, 2000). Its stability in aqueous food systems is limited and is dependent on pH, temperature, buffer type and concentration (Hutchinson and others 1999). It decomposes during excessive heating and loses its sweetening power. Thus it has limited use in baking and cooking applications.

Acesulfame-K

Acesulfame-K, the potassium salt of 3,4-dihydro-6-methyl-1,2,3-oxathiazine-4-one-2,2-dioxide (Fig. 2.7)., is a high intensity, non-caloric sweetener discovered in 1967 (the 'K' refers to potassium). Its sweetness is approximately 200 times that of sucrose, and is perceived quickly and without unpleasant delay. Acesulfame-K was first approved for use in certain foods by the FDA in 1988. It was later approved as a general purpose sweetener, except in meat and poultry, in 2003 (21CFR172.800). The ADI for acesulfame-K was set by the FDA at 15 mg/kg body weight/day.

In aqueous solutions with high concentrations of acesulfame-K, a bitter taste can sometimes be detected, but in foods, which generally have lower concentrations, this effect is not noticed. Acesulfame-K is stable at baking temperatures, therefore the sweet taste of acesulfame-K solutions does not decrease with rising temperatures to the extent of other artificial sweeteners (Lipinski 1986). Therefore, it can withstand high cooking and baking temperatures and is very stable under normal preparation and food processing conditions. Acesulfame-K can provide a synergistic sweetening effect when combined with other sweeteners, especially aspartame. This combination is commonly found in diet carbonated beverages.

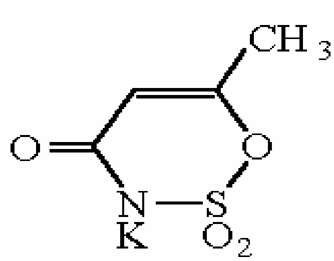


Figure 2.7 Chemical structure of acesulfame-K

Acesulfame-K is not metabolized by the body. Long-term toxicity, carcinogenicity and reproductive toxicity tests on acesulfame-K and possible degradation products demonstrated that acesulfame-K is acceptable and safe. It is quickly absorbed by the body and is excreted by the kidneys unchanged (Jung and others 1991). In a cytogenetic *in vivo* test on mice using acesulfame-K at 15, 30, 60, 450, 1500, and 2500 mg/kg body weight, positive results for chromosomal aberrations were found (Mukherjee and Chakrabarti 1997). At 15 and 30 mg/kg body weight, the number of aberrations was not significantly different from the control, but at doses of 60 mg or more, acesulfame-K was found to be genotoxic. Thus, as mentioned previously, the FDA set the ADI for acesulfame-K at 15 mg/kg/body weight/day.

Neotame

Neotame is the latest high intensity sweetener approved for use in the USA. It is a non-caloric sweetener composed of the same amino acids as aspartame, aspartic acid and phenylalanine (Figure 2.8) and is 7000 – 13,000 times sweeter than sucrose (ADA Reports 2004). It was approved by the FDA in 2002 for use as a sweetening agent and flavor enhancer in foods generally, except in meat and poultry (21CFR172.829). At the same time, the ADI was set by the FDA at 18 mg/day.

Neotame is partially absorbed in the small intestine, rapidly metabolized and excreted in the feces and urine. Like aspartame, a small amount of methanol is released when the sweetener is metabolized, along with a small amount of phenylalanine. Unlike aspartame, the amount of phenylalanine released is not clinically significant for people with PKU. Thus the labels for products with neotame do not need to include a warning. Neither neotame nor its metabolites are mutagenic, teratogenic, and carcinogenic (Nofre and Tinti 2000).

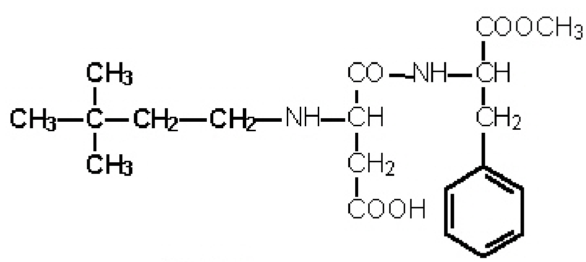


Figure 2.8 Chemical structure of neotame

Neotame is stable in dry and aqueous food systems, and is more stable than aspartame at neutral pH conditions. Prakash and others (2002) reported that it has a clean sweet taste similar to that of aspartame, but the sweetness develops gradually. It can enhance other acidic fruit flavors and mask undesirable flavors, such as the bitterness of caffeine and potassium chloride, as well as reduce the 'beany' taste of soy products. It does not have a synergistic effect with other high intensity sweeteners such as acesulfame-K and saccharin.

Splenda and Sucralose

Splenda is the brand name for a mixture of the non-caloric sweetener sucralose, a chlorinated derivative of sucrose (Figure 2.9), with the bulking agent maltodextrin. It is 600 times sweeter than sucrose (Sandrou and Arvanitoyannis 2000) and was first approved for use in foods by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 1990. In 1991, Canada's Health Protection Branch became the first national regulatory agency to endorse sucralose safety and permit its use in foods and beverages. In 1998, the United States FDA approved the use of sucralose in 15 food and beverage categories. Approval was later extended in August 1999, permitting sucralose use as a general-purpose sweetener in all foods, beverages, dietary supplements and medical foods (21CFR172.831). At the same time, the FDA set the ADI for sucralose at 5 mg/kg body weight/day.

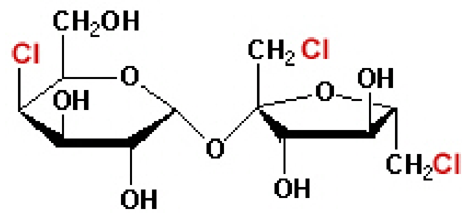


Figure 2.9 Chemical structure of sucralose

Net Energy, Metabolism and Effects of Sucralose

Sucralose is not broken down for energy in the body so it contributes no caloric value to the diet. Absorption, distribution, metabolism and elimination (ADME) studies in several animal species and man have shown that sucralose exhibits limited absorption, minimal metabolism of the absorbed material with no bioaccumulation, and rapid urinary excretion of unchanged sucralose (Goldsmith and Grice 2000, John and others 2000, Roberts and others 2000, Sims and others 2000, Wood and others 2000). Following an oral dose of sucralose, approximately 10-35% is absorbed in those laboratory animals tested and about 15% in humans.

Sucralose has been shown to be well tolerated in humans. Baird and others (2000) conducted two studies on sucralose tolerance in human subjects. One study was an ascending dose study conducted in eight subjects, in which sucralose was administered at doses of 1, 2.5, 5 and 10 mg/kg every other day for 9 days, followed by daily dosing at 2 mg/kg for 3 days followed by 4 days of continuous dosing of 5 mg/kg up to day 17. In the second study a total of 108 subjects were divided into two groups which consumed either sucralose or fructose twice daily in single blind fashion. Sucralose dosage levels were 125 mg/day for the first 3 weeks, 250 mg/day for the next 4 weeks, and 500 mg/day for a final 5 weeks. No adverse experiences were detected during the entire duration of both studies. Analysis of blood samples taken after the 10 mg/kg single oral dose showed peak sucralose concentrations occurred after 1 hour and decreased with almost complete elimination after 24 hours.

Sucralose has been shown to have no effect on glucose homeostasis, making it safe for use by individuals with type 2 diabetes. Grotz and others (2003) examined the effect of sucralose on glycemic control in diabetic individuals. In a double blind, randomized, parallel group design study, subjects were grouped and given either a placebo or sucralose pill (667 mg) for 13 weeks. Blood glucose homeostasis evaluation and documentation of adverse effects were preformed throughout treatment and during a 4 week follow up phase. Researchers found no significant differences between the sucralose and placebo group in fasting plasma glucose.

Stability

Sucralose has a high quality of sweetness, good water solubility and excellent stability in a wide range of processed foods and beverages. The sweetener is heat stable at cooking and baking temperatures. Miller (1991) studied the stability of aqueous, non-buffered sucralose at pH 3, 5 and 7, at 100°C for two hours. After 1 hour there was 98% sucralose remaining and after 2 hours, the greatest loss was 4% at pH 7. Barndt and Jackson (1990) studied sucralose degradation in various baked goods using ^{14}C-labeled sucralose. Cakes were baked at 180°C for 25 minutes, cookies were baked at 210°C for 8 minutes, and graham crackers were baked at 300°C for 4 minutes. No products other than sucralose were detected after baking, and the distribution of radioactivity corresponded well with the sucralose standard.

Food Applications of Sucralose and Splenda

When combined with other low calorie sweeteners, sucralose has a synergistic sweetening effect. Splenda can be used in a broad array of products including table top sweeteners, processed fruit, carbonated and non-carbonated beverages, chewing gum, baked goods, fruit spreads, milk products, frozen desserts, yogurts and salad dressings.

The Role of Sweeteners and Other Ingredients in Baked Products

A wide variety of bakery products can be found on the market, including breads, unsweetened rolls and buns, doughnuts, meat pies, dessert pies, pizza, quiche, crackers, biscuit, cookies and other products. There are several ways of grouping the products together. Classification can be based on product type such as unsweetened, sweetened or filled goods, the method of leavening (e.g. biological, chemical or unlevened), pH (separated into high acid, low acid, and nonacid or alkaline bakery products), and water activity (Table 2.8) with low moisture ($a_w < 0.6$), intermediate ($0.6 < a_w < 0.85$) and high moisture ($a_w > 0.85$). The basic ingredients used in the majority of baked products are flour, sugar, a lipid source such as shortening, eggs, a leavening agent such as baking powder, and water.

The ingredients are usually combined together to form a dough, which is the intermediate product in the transformation of flour to the final cooked product. The baking process transforms the dough from a viscoelastic solid to a solid mass with a characteristic texture. The rheological characteristics of the dough are important as they influence the machinability as well as the quality of the finished product. Manohar and Rao (2002) examined the inter-relationship between rheological characteristics of dough and quality of biscuits. They found that extrusion time, elastic recovery, apparent biaxial extensional viscosity, consistency and hardness of the dough are significantly correlated to the spread and density of biscuits, and that elastic recovery and cohesiveness of dough mainly influenced the thickness of biscuits.

Table 2.8 Water activity (a_w) range of selected bakery products

Product	a_w
Low moisture content	
Cookies	0.2 – 0.3
Crackers	0.2 – 0.3
Intermediate moisture content	
Chocolate coated doughnuts	0.82 – 0.83
Cream filled cake	0.78 – 0.81
Soft cookies	0.50 – 0.78
High moisture content	
Bread	0.96 – 0.98
Fruit pies	0.94 – 0.96
Cheese cake	0.91 – 0.95
Pizza	0.99

(Smith and others 2004)

Sugar is an important ingredient in baked products because it contributes to many aspects of the product, including texture, flavor, sweetness and color. Sugar generally has a tenderizing effect on baked products, due to competition with proteins for water. Water is needed for gluten development, but sugar binds water preferentially, making water less available (Conforti and Strait 1999). Therefore, the amount of sugar added to the product can be manipulated to produce an increase or reduction in the height of the final product. Similarly, sugar delays the diffusion of water into starch granules during gelatinization. Because alternative sweeteners may not have the same hygroscopic properties as the traditional sweeteners, they may or may not have this same effect in baked products.

Kulp and others (1991) reviewed the functionality of carbohydrate ingredients in specific bakery products. In bread, sugars serve as a source of fermentable solids, form color compounds in the crust, improve crumb texture and extend shelf life due to hygroscopicity. In cakes, sugars provide sweetness, affect the formation of cake structure, improve crumb texture and tenderness, promote good crumb color, and increase freshness by aiding in moisture retention and decreasing water activity of the product. In cookies, sugars generate flavor, affect cookie spread, control crispness and affect surface characteristics.

Role of sugar and sugar substitutes in cookies

Cookies, also referred to as semisweet biscuits (Charun and others 2000) or soft type biscuits (Giami and Barber 2004), are high-fat, high-sugar, and low moisture products. Formulations are typically 30–75% sugar, 30–60% fat, and 7-

20% water on a flour weight basis (Perry and others 2003). In cookies, the high percentage of sugar is incorporated to inhibit gluten development during dough mixing by competing with the flour for moisture.

Cookies tend to increase in diameter during baking, as opposed to height as the case with breads. This is attributed to the lower percentage of gluten, which forms a collapsible film instead of an elastic network. As a result, cookies show expansion followed by collapse during baking. An elastic network would exhibit elastic shrinkage after expansion and therefore no abrupt increase in diameter (Zoulias and others 2000).

When high intensity sweeteners are used, only small quantities are required as a replacement for sucrose because they are so much sweeter. The properties of the baked product are therefore not the same as when sucrose is used, because much smaller amounts of high intensity sweeteners are used. Bulking agents are required to compensate for lower sugar amounts. One such bulking agent is polydextrose, which is used to compensate for the loss in volume, and it also increases the onset and peak gelatiniztion temperatures of starch similar to those for sucrose (Freeman 1982).

Zoulias and others (2000) examined the effect of sugar replacement by fructose, polyols and acesulfame-K on dough rheology and physical properties of low-fat cookies in which polydextrose was used as a substitute for 35% of the fat content. The polyols used to replace sucrose included maltitol, lactitol, sorbitol, xylitol, and mannitol in equal amounts. In addition fructose was also used. They found that replacement with polyols affected the rheological properties of the dough along with the properties of the low-fat cookie. Replacement with maltitol and fructose resulted in doughs with higher values of hardness and consistency and low adhesiveness and cohesiveness, while lactitol, sorbitol and xylitol had the opposite effects. Lactitol and sorbitol improved the texture of the cookies making them softer and less brittle, whereas mannitol was not found suitable for cookie formulation as it restricts spread and imparts an unpleasant flavor and appearance to the cookies. Supplementation with acesulfame-K did not have a significant affect on the physical properties, but was found to increase sweetness and general acceptance, as determined by a trained sensory panel.

Curley and Hoseney (1984) examined the effects of adding high fructose corn syrup (HFCS) on cookie quality. They found that as the percentage of sugar replaced by HFCS increased to 50%, there was a linear increase in dough stickiness. This was attributed to the amount of sugar that was able to dissolve during creaming. All HFCS is able to dissolve during creaming, which results in increased stickiness and softness of the dough. With sucrose, there is much less that dissolves during the creaming stage, and so the dough is not as sticky. When Curley and Hoseney looked at the diameter and height of cookies produced from sucrose and fructose, they found cookie diameter gradually decreased with increasing fructose percentages while cookie thickness increased (up to 50%).

Drewnowski and others (1998) examined the effect of reducing sugar and fat content in different types of cookies, on product quality and preference using sensory evaluations. The cookie recipes produced tollhouse cookies, peanut butter cookies, oatmeal cookies, brownies and biscotti. The recipes were altered to give a 25% reduction in sugar, fat, both sugar and fat, and a 50% reduction in fat. Reducing fat content by 25% had no impact on overall product acceptability, which declined only when fat was reduced by 50%. In contrast, reducing sugar content of the cookies by 25% had an immediate adverse impact on overall acceptability ratings. Overall acceptability and liking for cookie texture and flavor all declined with reduced sugar content regardless of cookie type, while remaining relatively unaffected by a 25% reduction in fat. This indicates that consumers may be more sensitive to small variations in sugar content, while changes in fat are often difficult to detect in solid foods, since no single attribute can be unambiguously associated with fat content.

With the importance that sugars play in texture and taste of baked products, it is important to enhance our knowledge of the effects that different sucrose-replacers have on their properties. One goal of food science is to reduce the amounts of digestible sugars in food products so that they are healthier. Using either tagatose or Splenda would result in products with lower metabolizeable sugars. Thus the objective of this research project was to evaluate the potential of D-tagatose and Splenda as a substitute for sugar (sucrose) in a baked product, by evaluating the physical and sensory properties of cookie dough and baked cookies prepared with varying amounts of the sugar replacers.

CHAPTER 3

METHODS

To address the objectives presented previously, a series of studies were conducted to evaluate properties of both the cookie dough and baked cookies. The procedures are described below.

Cookie Formulation & Preparation

The formula and method of cookie preparation were as described by McWatters and others (2003). The basic ingredients purchased from a local supermarket in Auburn, Alabama (Kroger) were: all-purpose flour (White Lily), 75.5 g; granulated sugar, 75.0 g (Kroger brand); hydrogenated vegetable shortening (Crisco), 47.0 g; egg (whole, fresh), 24.0 g; cream of tartar (Kroger brand), 1.6 g; baking soda (Arm & Hammer), 1.0 g; cinnamon (Kroger brand), 0.5 g; and iodized salt (Kroger brand), 0.4 g. Fructose and Splenda were also purchased from local supermarkets (Bruno's and Kroger), while tagatose was donated by its U.S. distributor Arla Food Ingredients (Basking Ridge, NJ).

The dry ingredients were sifted together. The sugar and shortening were creamed together on low for 30 seconds, and then medium for 2 minutes using a

General Electric hand-held mixer. The 24.0 g portion of whole egg, previously beaten with wire whisk for 30 seconds and weighed in a bowl, was added to the creamed sugar/shortening mixture and everything was creamed together for an additional one and a half minutes. Half of the sifted dry ingredients were added to this mixture, which was beaten on low for 10 seconds and then on medium for an additional 10 seconds. The rest of the dry ingredients were then added and the entire mixture beaten on high for 10 seconds.

The formulation varied only according to the amount and type of sweetener included in the recipe. The term 'sugar' in the above recipe refers to natural sugars sucrose, fructose and tagatose, as well as the high intensity sweetener Splenda. Sucrose was replaced at the 25, 50, 75 and 100% level using fructose and tagatose (Table 3.1). Since Splenda is a high intensity sweetener, the level of replacement was modified according to the instructions of the manufacturer. Based on this information, 10 g of Splenda was considered equivalent to 75 g sucrose. Therefore, 25% replacement means that 2.5 g Splenda was used to replace 18.75 g of sucrose.

After mixing, the dough was placed on sheets of wax coated paper and rolled between two cutting boards to give a uniform thickness of 8 mm. The dough was cut with a circular wire cookie cutter with a diameter of 50 mm. The cut dough was baked on an aluminum sheet at 375°F (190.57°C) in a conventional electric oven for 15 minutes if they contained 100% sucrose, 12 minutes if they contained tagatose or fructose and 18 minutes if they contained Splenda. These times were selected to give approximate equal doneness as based on visual inspection of the cookies. After baking, the samples were cooled and stored at room temperature in Ziploc bags until analysis, which was conducted within 12 hours.

Table 3.1 Sucrose, tagatose, fructose and Splenda levels* of the cookie recipe.

Percent replacement of sucrose (%)	0	25	50	75	100
Amount of sucrose (g)	75	56.25	37.50	18.75	-
Amount of fructose and tagatose (g)	0	18.75	37.50	56.25	75.00
Amount of Splenda (g)	0	2.50	5.00	7.50	10.00

* Note sucrose was combined with only one of the sugar replacers in a given recipe.

Baking time determination

As mentioned previously, visual observations of the dough during baking indicated that the cookies needed to be baked at different times. To further explore the extent of doneness, a time-temperature test was conducted where the internal temperature of cookies made using 100% sucrose, fruct tagatose, Splenda and fructose were measured after different baking times. Cookie doughs were prepared as described above, placed on an aluminum cookie sheet, and baked at 375ºF. At four different times (9, 12, 15 and 18 min), cookies were removed from the oven and their internal temperature measured using a thermocouple inserted into the middle of the cookie.

The values obtained (Table 3.2) indicate that at 9 minutes, the internal temperature of all the cookies was below the boiling point of pure water (212°F); their inside structures were fluid-like and therefore were not completely baked. At 12 minutes, the internal temperature of cookies made with Splenda and sucrose remained slightly below the boiling point of water, while the temperatures of cookies made with tagatose and fructose were approximately 230°F. The tagatose- and fructose-containing cookies had a dry internal structure while the other cookies remained moist and under-cooked. At 15 minutes, the sucrose containing cookies obtained a dry interior while the cookies prepared with tagatose and fructose were becoming unacceptably dark. Cookie dough made with Splenda did not attain an internal temperature similar to that of the other cookie types (i.e., around 230ºF) until 18 minutes, at which time its interior was dry. These results support the visual observations in choosing baking times of 12 minutes for cookies prepared using fructose and tagatose, 15 minutes for those containing sucrose and 18 minutes for cookies made with Splenda.

Table 3.2 Internal temperature (°F) of the center of cookies baked at 375°F as a function of time.

Sweetener	9 min	12 min	15 min	18 min
Sucrose	213	209	242	249
Tagatose	210	230	227	248
Splenda	210	215	213	227
Fructose	209	227	238	244

Cookie Dough Analysis using Texture Profile Analysis (TPA)

Texture analysis on cookie dough was performed using a Texture Analyzer TA-HDi (Texture Technologies Corp, Scarsdale NY 10583). A two bite TPA was conducted on the dough according to the method adapted from Zoulias and others (2000). The dough formatted into 50 x 8 mm diameter disks was placed on the Texture Analyzer platform and a 3 inch cylindrical acrylic probe was moved down to the surface. The analyzer was set at a 'return to start' cycle, a pre-test speed of 2.00 m/s, a test and post-test speed of 1.60 mm/s, distance of 2.4 mm, load cell of 500 kg, and a time of 2.00 seconds between the two compressions. The recorded force-time plots (Figure 3.1) were analyzed for hardness, which is the maximum resistance to the first compression; adhesiveness, which is the area of the first adhesion peak; springiness which is the measurement of how well the product springs back after the first compression; cohesiveness, which is how well the product withstands a second deformation relative to how it behaved under the first deformation; chewiness which applies only to solid products and is measured as the product of hardness, cohesiveness and springiness; and resilience which is the resistance of the product to the first deformation. These properties were measured from readings taken from the force-deformation plots according to Table 3.3.

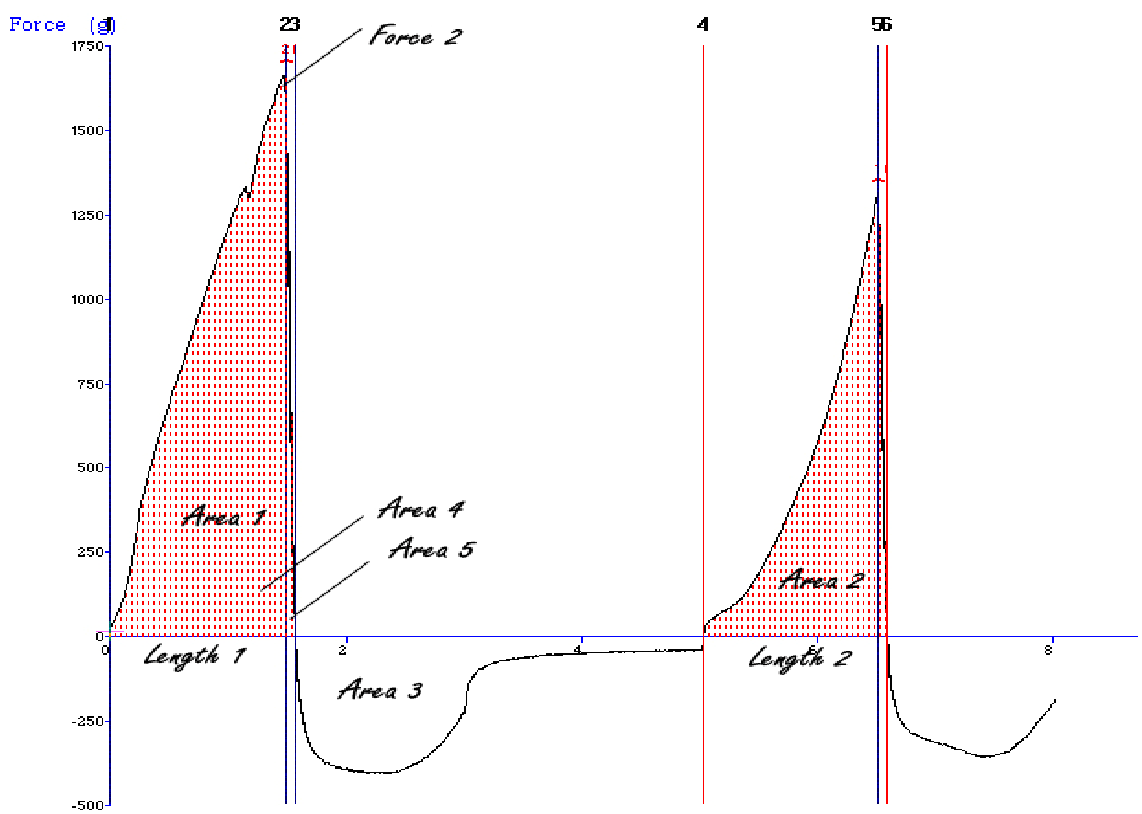


Figure 3.1 Sample TPA plot for cookie dough

Table 3.3 Texture property measurements on the TPA graph.

Texture Property	Corresponding graphed output
Hardness	Force 2
Adhesiveness	Area 3
Cohesiveness	Area 2/Area 1
Springiness	Length 2/Length 1
Chewiness	hardness x cohesiveness x springiness
Resilience	Area 5/Area 4

Determination of Physical Properties of the Cookies

The physical properties of the baked cookies that were measured included diameter, height, color, and hardness. Height and diameter of the cookies were measured using a vernier caliper. The diameter of a cookie was measured, rotated and measured again. This was done using three cookies from each batch, and the average of all the measurements was taken as the final diameter. In order to measure height, a modified procedure presented by Zoulias and others (2000) was followed. Three cookies were stacked one on top of the other, measured and then restacked and re-measured. The average height of the cookie was the reading obtained divided by 3. Spread ratio was calculated as diameter/height. A Hunter colorimeter was used to measure the L, a, and b values of the top surface of three cookies. Standard white and black tiles were used to calibrate the colorimeter.

A 'snap test' was conducted on the cookies in order to determine the maximum force required to break the cookies. This was done using the Texture Analyzer previously described, fitted with a sharp-blade cutting probe, 6 cm long and 0.1 mm thick, as described by Zoulias and others (2002). The analyzer was set at a 'return to start' cycle, a pre and post test speed of 2.00 mm/s, a test speed of 5.00 mm/s, distance of 10.00 mm and a load cell of 500 kg.

Sensory Evaluation of Cookies Baked Using Tagatose And Sucrose

An untrained test panel (n = 53) was recruited from students and faculty of Auburn University, in order to evaluate consumer acceptability of cookies made with 100% tagatose, 100% sucrose, and a 50-50 combination of tagatose and sucrose, all baked according to the recipe described previously. The criteria for selection of the panelists were based on age being between 19-60 years of age and a willingness to participate. A sample of each cookie was placed on a white plate divided into three sections identified with a random three digit code number. Panelists were given a packet containing an IRB approval letter and a questionnaire designed to collect demographic information, cookie consumption habits and an evaluation form for each cookie sample (Appendix A). On the evaluation form, panelists were instructed to evaluate the color, sweetness, texture and overall acceptability of the cookies. A nine point categorical hedonic scale was used, anchored by 'Dislike extremely' and 'Like extremely'. Water was provided to rinse the mouth between evaluations and covered expectoration cups were also provided if panelists did not wish to swallow the samples.

Replication & Statistical Analysis

There were four types of sugars (sucrose, fructose, Splenda and tagatose), each done at 4 levels of sugar replacement (25, 50, 75 and 100%) to give 16 recipes. Each recipe was baked at least three times, each on a separate day. Analyses were conducted in triplicate every time a recipe was baked. The exact number of replicates is indicated in the results. The variability of measurements taken within a given day are tabulated and presented in the appendices.

The experimental design for the physical and rheological measurements was a two factor multivariate design, while for the sensory analysis, the design was repeated measures ANOVA. Analysis of the data was conducted using SAS 9.1 software. Both MANOVA and ANOVA were used to calculate significant differences at $p \leq 0.05$. Comparisons were made using LS Means adjusted with Tukey-Kramer test of multiple comparisons.

CHAPTER 4

RESULTS AND DISCUSSION

Cookie Dough TPA Results

TPA provided estimates of hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience of the cookie dough prepared with each type of sugar. Table 4.1 compares the mean values of the TPA parameters of dough prepared with 100% sucrose to values obtained from dough where sucrose is replaced by a certain percentage of another sweetener. Table 4.2 compares the values obtained as the concentration of a particular sugar changes.

Hardness

Hardness is the force required to compress a sample on the first compression, which is analogous to the 'first bite'. Figure 4.1 shows graphically the variation in hardness of cookie dough made using the various sweeteners. Using 100% tagatose resulted in cookies with the hardest cookie dough (3258 ± 923 g), but this value was not significantly different ($p > 0.05$) from the hardness of cookie dough produced with sucrose (2683 ± 317 g) or Splenda (2782 ± 369 g).

Table 4.1 Comparison of textural properties of cookie dough made using sucrose with dough made using sucrose in combination with fructose, Splenda and tagatose

Sweetener	Percent replacement of sucrose (%)	n	Hardness (g)	Adhesiveness (g/s)	Springiness	Cohesiveness	Chewiness	Resilience
Sucrose	n/a	18	2683 ± 317^{a}	354 ± 128^{a}	0.78 ± 0.09^{a}	0.39 ± 0.08^{a}	1326 ± 147^{a}	0.05 ± 0.01^{a}
Fructose	25	9	1179 ± 94^{b}	433 ± 75^{a}	0.94 ± 0.20^{a}	0.36 ± 0.06^{a}	459 ± 68^{b}	0.03 ± 0.00^{b}
Splenda	25	15	2211 ± 872^{c}	365 ± 82^{a}	0.84 ± 0.15^{a}	0.38 ± 0.07^{a}	1021 ± 464^{a}	0.04 ± 0.00^{ab}
Tagatose	25	15	1627 ± 887^{bc}	363 ± 124^{a}	0.90 ± 0.13^{a}	0.48 ± 0.11^{b}	885 ± 556^{ab}	0.05 ± 0.01^{a}
Sucrose	n/a	18	2683 ± 317^{a}	354 ± 128^{ab}	0.78 ± 0.09^{ab}	0.39 ± 0.08^{ab}	1326 ± 147^{a}	0.05 ± 0.01^{a}
Fructose	50	10	690 ± 117^{b}	479 ± 63^{a}	0.89 ± 0.14^{abc}	0.47 ± 0.08^{b}	365 ± 74^{b}	0.03 ± 0.01^{b}
Splenda	50	9	2447 ± 239^{ac}	261 ± 43^{b}	0.69 ± 0.05^{b}	0.35 ± 0.03^{a}	1215 ± 77^{ac}	0.04 ± 0.00^{ab}
Tagatose	50	20	1605 ± 574^{c}	352 ± 83^{ab}	0.94 ± 0.10^{c}	0.44 ± 0.03^{ab}	778 ± 378^{bc}	0.04 ± 0.01^{ab}
Sucrose	n/a	18	2683 ± 317^{a}	354 ± 128^{a}	0.78 ± 0.09^{a}	0.39 ± 0.08^{a}	1326 ± 147^{a}	0.05 ± 0.01^{a}
Fructose	75	9	618 ± 67^{b}	509 ± 80^{a}	0.95 ± 0.10^{ab}	0.44 ± 0.04^{a}	292 ± 58^{b}	0.03 ± 0.00^{b}
Splenda	75	12	2392 ± 644^{ac}	417 ± 93^{a}	0.90 ± 0.12^{ab}	0.41 ± 0.02^{a}	1125 ± 451^{ac}	0.04 ± 0.00^{ab}
Tagatose	75	12	1822 ± 247^{c}	408 ± 53^{a}	0.97 ± 0.06^{b}	0.42 ±0.02^{a}	797 ± 140^{bc}	0.04 ± 0.01^{ab}
Sucrose	n/a	18	2683 ± 317^{a}	354 ± 128^{a}	0.78 ± 0.09^{a}	0.39 ± 0.08^{a}	1326 ± 147^{a}	0.05 ± 0.01^{a}
Fructose	100	12	570 ± 47^{b}	629 ± 39^{b}	0.95 ± 0.12^{ab}	0.51 ± 0.12^{bc}	303 ± 52^{b}	0.03 ± 0.01^{b}
Splenda	100	12	2782 ± 369^{a}	637 ± 246^{b}	0.97 ± 0.05^{b}	0.56 ± 0.07^{c}	1586 ± 139^{a}	0.06 ± 0.01^{a}
Tagatose	100	16	3258 ± 923^{a}	425 ± 136^{a}	0.79 ± 0.12^{a}	0.42 ± 0.09^{ab}	1689 ± 458^{a}	0.06 ± 0.01^{a}

Results are presented as mean ± std

$^{a\ b\ c}$ means with differing superscripts are significantly different ($p < 0.05$) from values of sugars at the same percentage and 100% sucrose

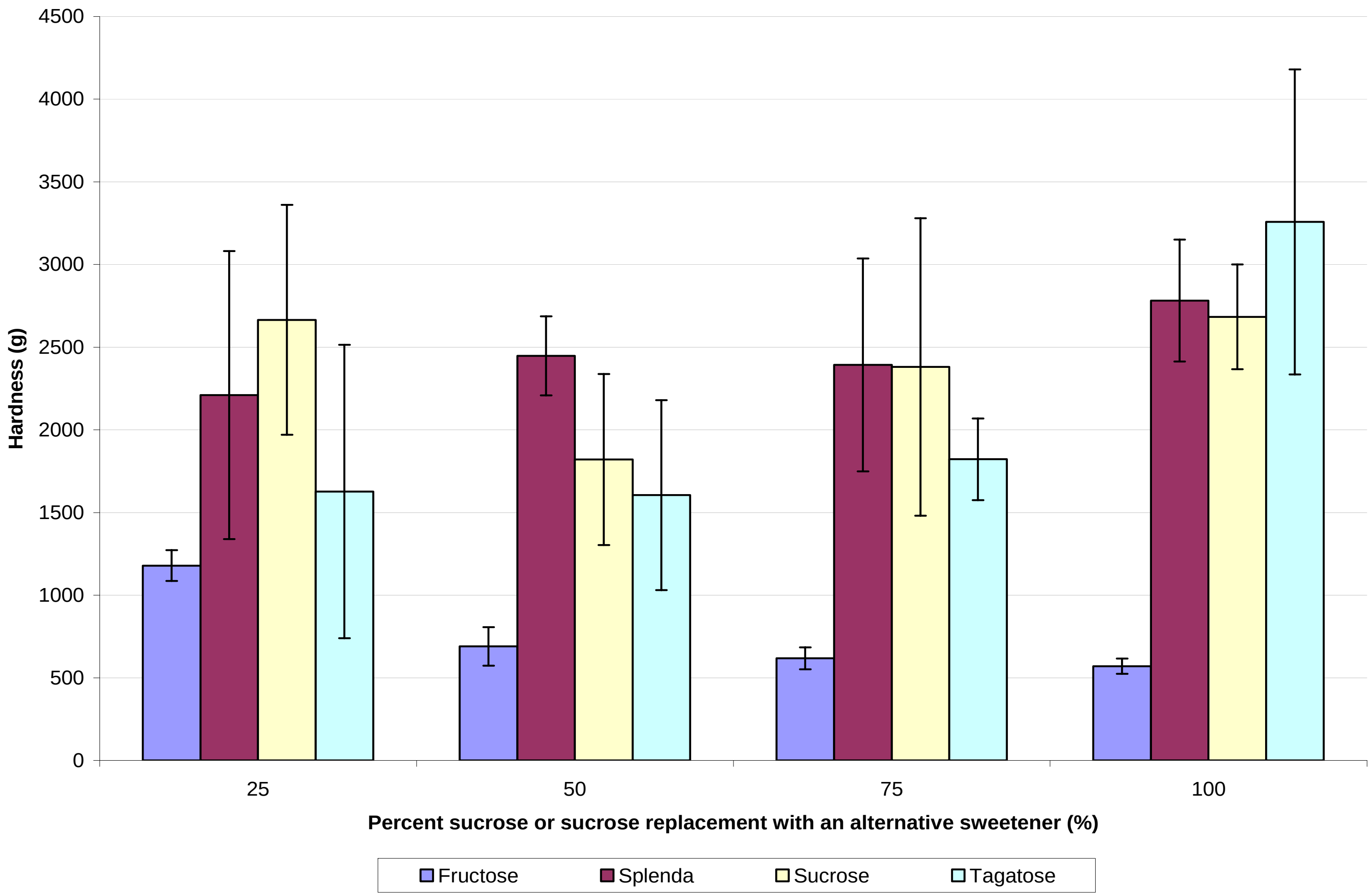
Table 4.2 Comparison of textural properties of cookie dough made using sucrose with dough made using sucrose in combination with fructose, Splenda and tagatose, as a function of sweetener concentration

Sweetener	Percent replacement of sucrose (%)	n	Hardness (g)	Adhesiveness (g/s)	Springiness	Cohesiveness	Chewiness (g)	Resilience
Sucrose	100	18	2683 ± 317^{a}	354 ± 128^{a}	0.78 ± 0.09^{a}	0.39 ± 0.08^{a}	1326 ± 147^{a}	0.05 ± 0.01^{a}
Sucrose	75	13	2380 ± 900^{ab}	357 ± 103^{a}	0.82 ± 0.20^{a}	0.40 ± 0.06^{a}	1299 ± 780^{a}	0.05 ± 0.01^{a}
Sucrose	50	12	1820 ± 518^{b}	297 ± 30^{a}	0.88 ± 0.09^{a}	0.44 ± 0.06^{a}	915 ± 259^{a}	0.05 ± 0.00^{a}
Sucrose	25	9	2665 ± 695^{ab}	386 ± 105^{a}	0.84 ± 0.18^{a}	0.44 ± 0.11^{a}	1371 ± 281^{a}	0.05 ± 0.01^{a}
Fructose	100	12	570 ± 47^{a}	629 ± 39^{a}	0.95 ± 0.12^{a}	0.51 ± 0.12^{a}	303 ± 52^{a}	0.03 ± 0.01^{a}
Fructose	75	9	618 ± 67^{a}	509 ± 80^{ab}	0.95 ± 0.10^{a}	0.44 ±0.04^{ab}	292 ± 58^{a}	0.03 ± 0.00^{a}
Fructose	50	10	690 ± 117^{a}	479 ± 63^{ab}	0.89 ± 0.14^{a}	0.47 ± 0.08^{ab}	365 ± 74^{a}	0.03 ± 0.01^{a}
Fructose	25	9	1179 ± 94^{a}	433 ± 75^{b}	0.94 ± 0.20^{a}	0.36 ± 0.06^{b}	459 ± 68^{a}	0.03 ± 0.00^{a}
Splenda	100	12	2782 ± 369^{a}	637 ± 246^{a}	0.97 ± 0.05^{a}	0.56 ± 0.07^{a}	1586 ± 139^{a}	0.06 ± 0.01^{a}
Splenda	75	12	2392 ± 644^{a}	417 ± 93^{b}	0.90 ± 0.12^{a}	0.41 ± 0.02^{b}	1125 ± 451^{ab}	0.04 ± 0.00^{b}
Splenda	50	9	2447 ± 239^{a}	261 ± 43^{b}	0.69 ± 0.05^{b}	0.35 ± 0.03^{b}	1215 ± 77^{ab}	0.04 ± 0.00^{b}
Splenda	25	15	2211 ± 872^{a}	365 ± 82^{b}	0.84 ± 0.15^{ab}	0.38 ± 0.07^{b}	1021 ± 464^{b}	0.04 ± 0.00^{b}
Tagatose	100	16	3258 ± 923^{a}	425 ± 136^{a}	0.79 ± 0.12^{a}	0.42 ± 0.09^{a}	1689 ± 458^{a}	0.06 ± 0.01^{a}
Tagatose	75	12	1822 ± 247^{b}	408 ± 53^{a}	0.97 ± 0.06^{b}	0.42 ± 0.02^{a}	797 ± 140^{b}	0.04 ± 0.01^{b}
Tagatose	50	20	1605 ± 574^{b}	352 ± 83^{a}	0.94 ± 0.10^{b}	0.44 ± 0.03^{a}	778 ± 378^{b}	0.04 ± 0.01^{b}
Tagatose	25	15	1627 ± 887^{b}	363 ± 124^{a}	0.90 ± 0.13^{ab}	0.48 ± 0.11^{a}	885 ± 556^{b}	0.05 ± 0.01^{ab}

Results are presented as mean ± std

$^{a\ b}$ means with differing superscripts are significantly different ($p < 0.05$) within the same sugar type

Figure 4.1 Mean hardness (± standard deviation) of cookie dough made using fructose, Splenda, sucrose and tagatose.



Replacing sucrose with fructose produced the least hard cookie dough (570 ± 47 g). This hardness was significantly lower than that of cookie dough produced using all the other sweeteners ($p < 0.05$). Replacing 100% sucrose with Splenda produced cookie dough with similar hardness to both sucrose and tagatose (2782 ± 369, 2683 ± 317 and 3258 ± 923 g respectively).

When sucrose was partially replaced by the other sweeteners, a softening effect on the cookie dough was generally observed. Fructose had the most significant softening effect on the cookie dough when it was used to replace sucrose. When 25% sucrose was replaced with fructose, the hardness of the cookie dough decreased by 44% from 2683 ± 317 g to 1179 ± 94 g. As the level of sucrose replaced by fructose increased, the hardness of the cookie dough continued to decrease slightly, but not significantly ($p > 0.05$).

Although tagatose produces significantly harder cookie dough when it is used to totally replace, when it is used in combination with sucrose, a softening effect is actually observed. For example, when 25% sucrose is replaced with tagatose, the dough becomes significantly softer ($p < 0.05$) than cookie dough made using only sucrose (1627 ± 887 and 2683 ± 317 g respectively). The dough remains significantly softer even with 75% replacement of sucrose with tagatose (1822 ± 247 g).

Using a combination of sucrose with Splenda produced cookie dough which was the most similar in hardness to dough made using only sucrose.

Replacing sucrose with 25% Splenda produced cookie dough which was significantly less hard than using sucrose only (2211 ± 872 g). As the amount of Splenda incorporated into the recipe increased to 50% and above, the difference in hardness was no longer significant.

When sucrose was decreased in the recipe without replacement, a slight decrease in hardness was observed. Manohar and Rao (1997) found that decreasing the amount of added sugar made biscuit dough softer. In our results, only when sucrose is totally replaced with 100% tagatose is significantly harder dough produced.

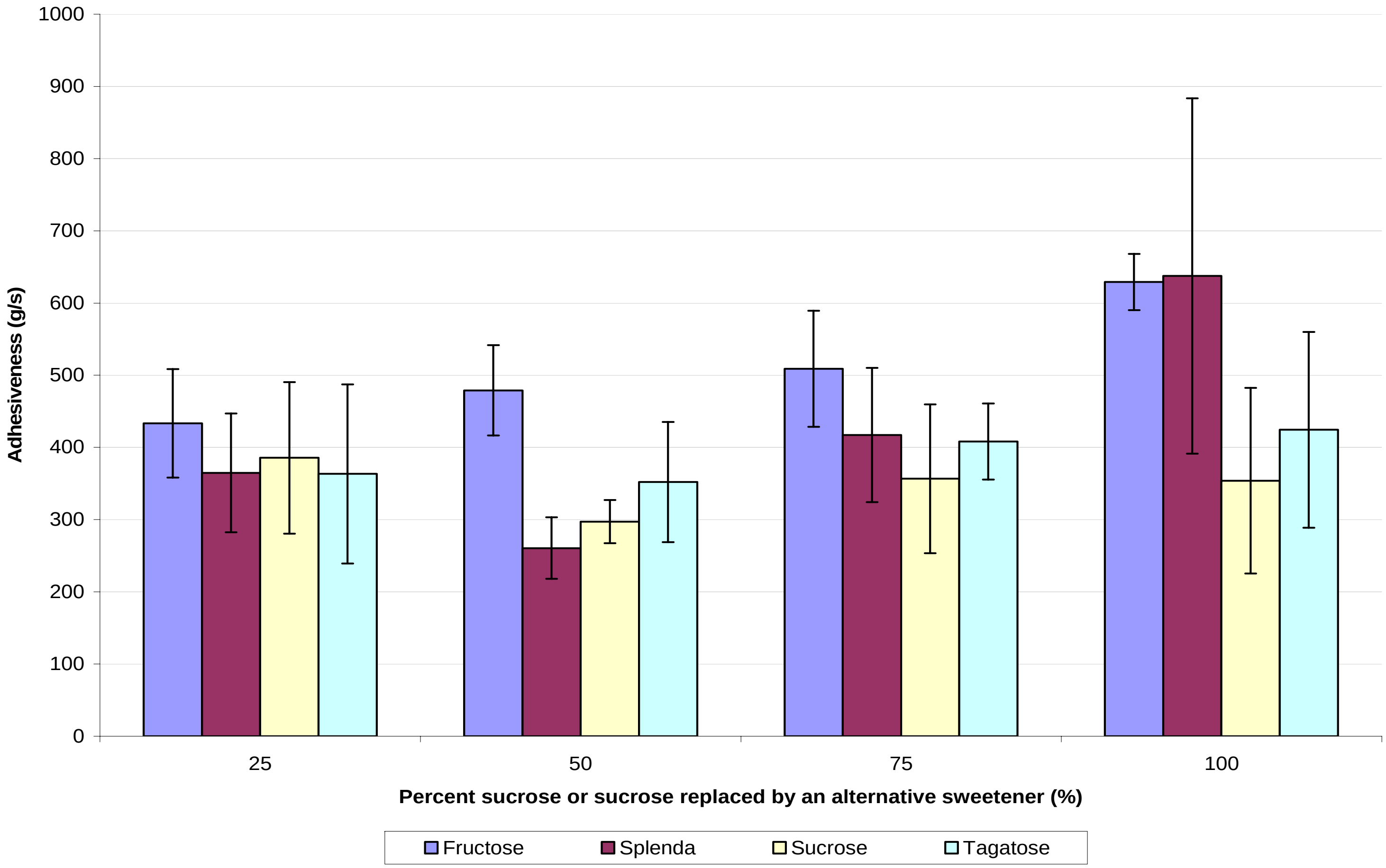
The hardness of cookies (both the dough and the baked product) mainly results from the development of the flour gluten (protein) network. Sugar acts as a tenderizer by absorbing moisture, which is necessary for the network development. Because sugar is more hygroscopic than gluten, it inhibits gluten development as well as delays starch gelatinization during baking. Therefore hardness of the dough can be thought of as a function of the solubility of the sweeteners (Zouilas and others 2000); the greater the solubility, the lower the hardness. Fructose is more soluble than sucrose at 789.4 and 199.4% g solids/g water at 20°C (Kulp and others 1991), and tagatose is the least soluble (58% w/w at 21°C) (Levin 2002). Splenda does not have a significant effect on the hardness, because of the small amount that is used compared to the other sweeteners.

Adhesiveness

Adhesiveness is the ease of removal of the dough from a surface after the first compression which is analogous to ease of removal of a product completely from the palate after the first bite. Figure 4.2 shows graphically the variation in the adhesiveness values for cookie dough made using the various sweeteners.

All the various sugar combinations produced cookie dough with similar adhesiveness values with the exception of 100% fructose and Splenda (629 ± 39 and 637 ± 246 g/s respectively), which produced cookie dough which was significantly more adhesive than cookie dough made with 100% sucrose (354 ± 129 g/s respectively). Cookie dough made from 100% fructose was so sticky that it was almost unmanageable. Cookie dough made with 100% tagatose was similar in adhesiveness to dough made from sucrose (425 ± 136 and 354 ± 131 g/s respectively). As sucrose was increasingly replaced by Splenda and fructose, there was a trend towards an increase in the adhesiveness of the cookie dough produced, however, this difference was not statistically significant ($p > 0.05$) until Splenda and fructose were used to totally replace sucrose.

Figure 4.2 Mean adhesiveness (± standard deviation) of cookie dough made using fructose, Splenda, sucrose and tagatose.



Adhesiveness is related to the amount of sugar that dissolves prior to baking, which is similar to the hardness values discussed previously (Curley and Hoseney 1984). When sugars are dissolved, part of the moisture in the food system is displaced with the sugars resulting in an overall increase in total solution volume. This results in a more adhesive (and softer) dough (Curley and Hoseney 1984). Since fructose is completely dissolved during the creaming process, as previously mentioned, it produces a very adhesive dough. It was expected that Splenda would produce dough similar in adhesiveness to sucrose, or even slightly less adhesive, since the volume of sugar removed is not replaced. However, the values varied widely, which may account for the unexpected higher adhesiveness observed (637 ± 246 g/s).

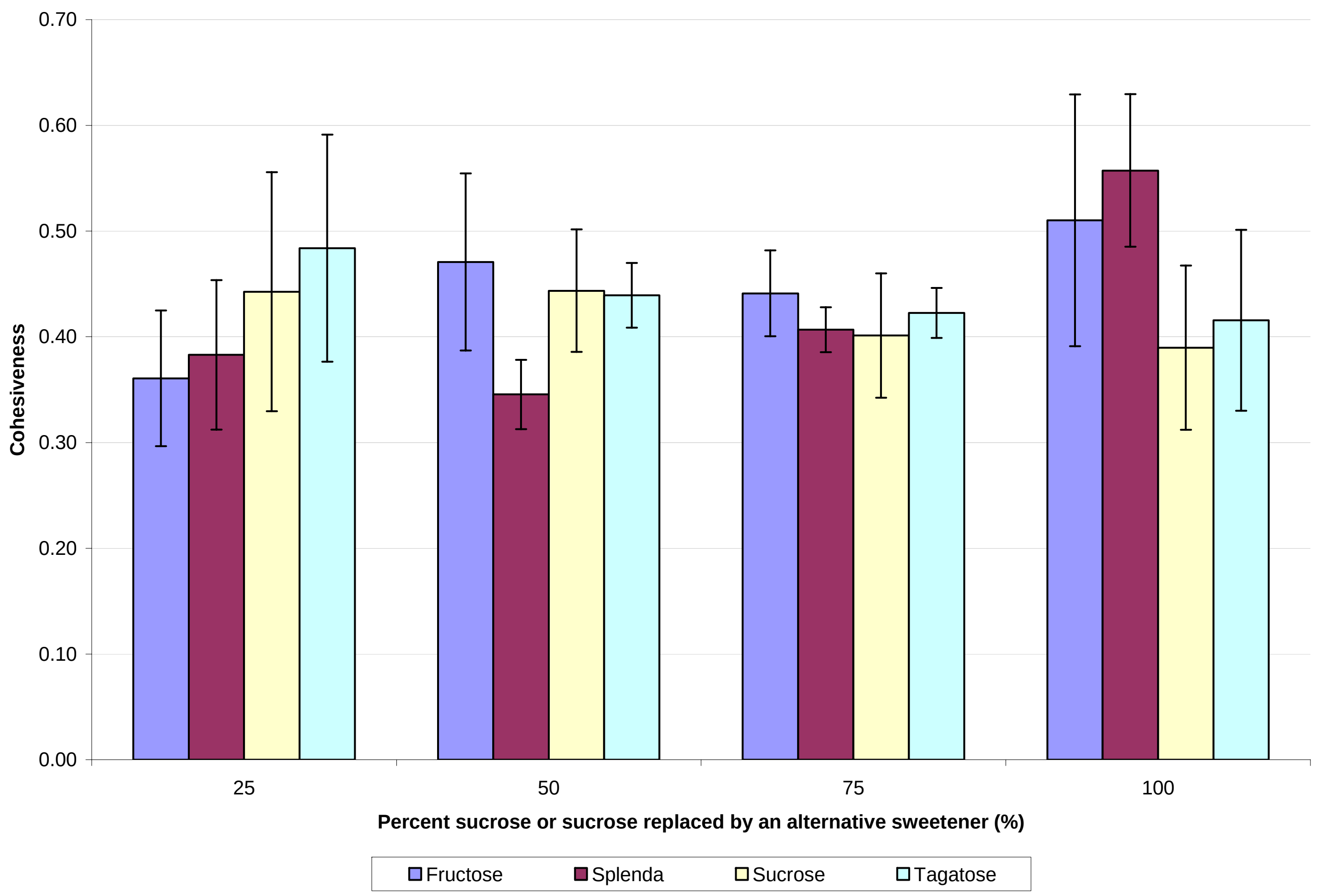
Cohesiveness

Cohesiveness represents how well the product withstands a second deformation relative to how it behaved under the first deformation. Lower cohesiveness values indicate more crumbly or brittle dough. As the amount of sucrose used decreases without replacement, there is a slight but not significant increase in cohesiveness of the dough. Development of the flour gluten network is responsible for cohesiveness and much of the structure of baked products. The development of the gluten network starts to occur during the mixing process as the proteins are stretched out. Incorporation of sugars interrupts and interferes with the development of the network. Therefore, we expect that as the amount of sucrose incorporated decreases, there should be less disruption resulting in an increase in cohesiveness. Because development of the gluten network is initialized mainly during kneading, and not much kneading was involved in producing the cookie dough, significant differences were not expected.

Cookie dough made with 100% fructose and Splenda showed the greatest cohesiveness (0.51 ± 0.12 and 0.56 ± 0.07, respectively), which was significantly greater than dough made with sucrose (0.39 ± 0.08) (Table 4.1). Although replacing sucrose with fructose and Splenda significantly increased the cohesiveness of the dough, combinations of sucrose and those sweeteners did not have a significant effect on cohesiveness. As the percent of sucrose replaced with fructose and Splenda increased, there was a slight but not significant increase in cohesiveness. In contrast, when just 25% sucrose was replaced by tagatose, a significant ($p < 0.05$) increase in cohesiveness was observed (0.39 ± 0.08 and 0.48 ± 0.11, respectively). As sucrose was increasingly replaced by tagatose, cohesiveness of the dough decreased slightly, but not significantly when compared to 100% tagatose, but the values became similar to dough made using 100% sucrose. The trends in cohesiveness data can be seen in Figure 4.3.

Generally, cookie dough which was more adhesive also appeared to be more cohesive. This may be because the dough structure is held together by the gluten network, which is influenced by the hygroscopic nature of the sugars.

Figure 4.3 Mean cohesiveness (± standard deviation) of cookie dough made using fructose, Splenda, sucrose and tagatose.



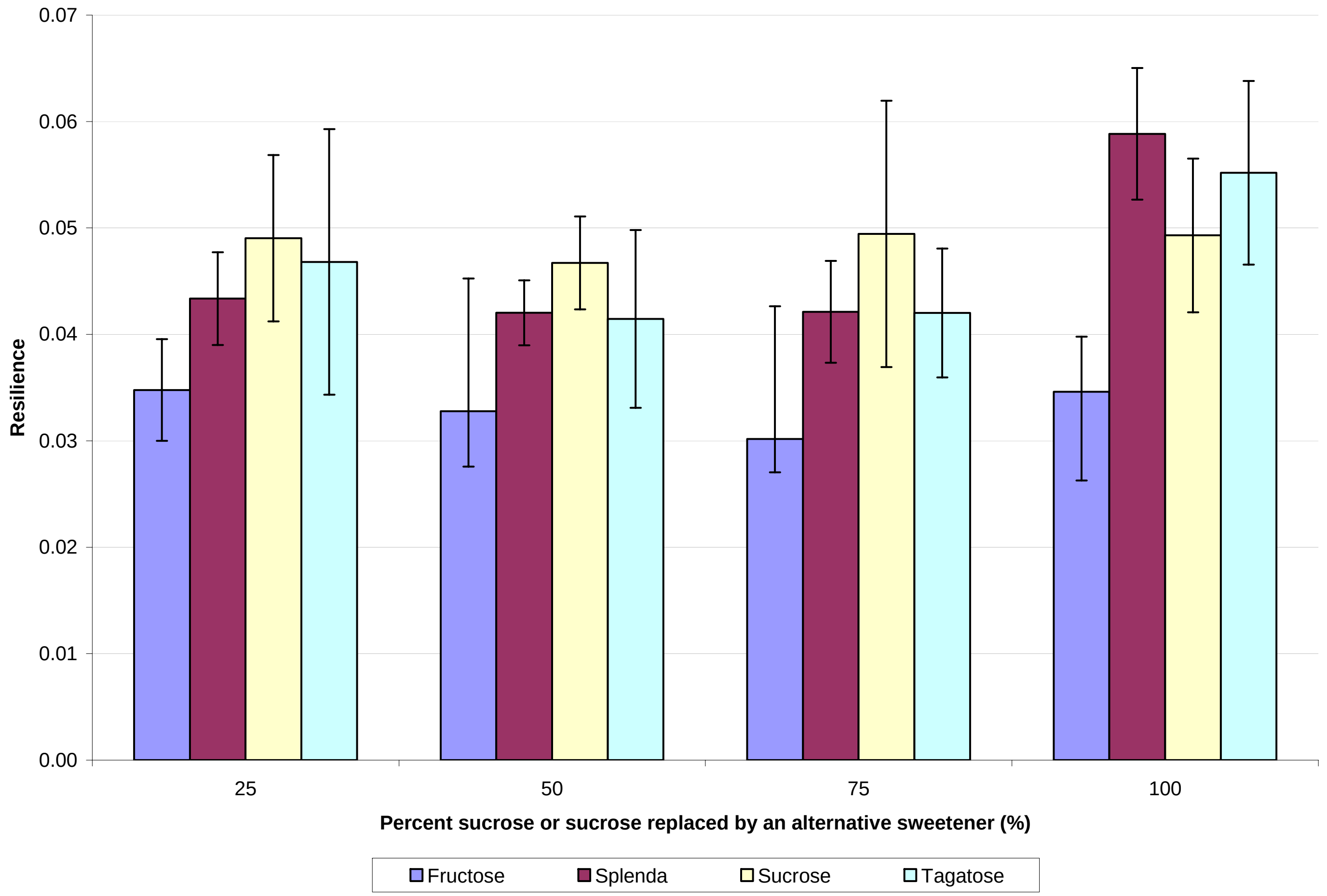
Resilience

Resilience represents how well the cookie dough regains its original shape after the first compression. Cookie dough made with fructose showed significantly ($p < 0.05$) lower resilience (0.03 ± 0.01) than dough made with 100% sucrose (0.05 ± 0.01), which did not change upon combination with sucrose (Figure 4.4). This can be attributed to the increased adhesiveness but lower hardness of cookie dough made with fructose. These two properties make for a very malleable dough which will readily cling to surfaces, and is less apt to regain its original shape as readily as cookie dough made with the other sweeteners.

Cookie dough made with 100% Splenda and tagatose had slightly greater resilience values than dough made with 100% sucrose (0.06 ± 0.01 and 0.05 ± 0.01, respectively). When sucrose was used in combination with Splenda and tagatose, the cookie dough had a slightly lower, but not significantly different, resilience. When sucrose was combined with fructose, the resilience was always significantly lower than when sucrose was used alone.

There is not much gluten network development in cookie dough due to the large amount of sugars in cookie recipes and the short kneading time, so the resilience values were very low. Thus there will be less obvious resilience differences in cookie dough than other products such as yeast bread dough.

Figure 4.4 Mean resilience (± standard deviation) of cookie dough made using fructose, Splenda, sucrose and tagatose.

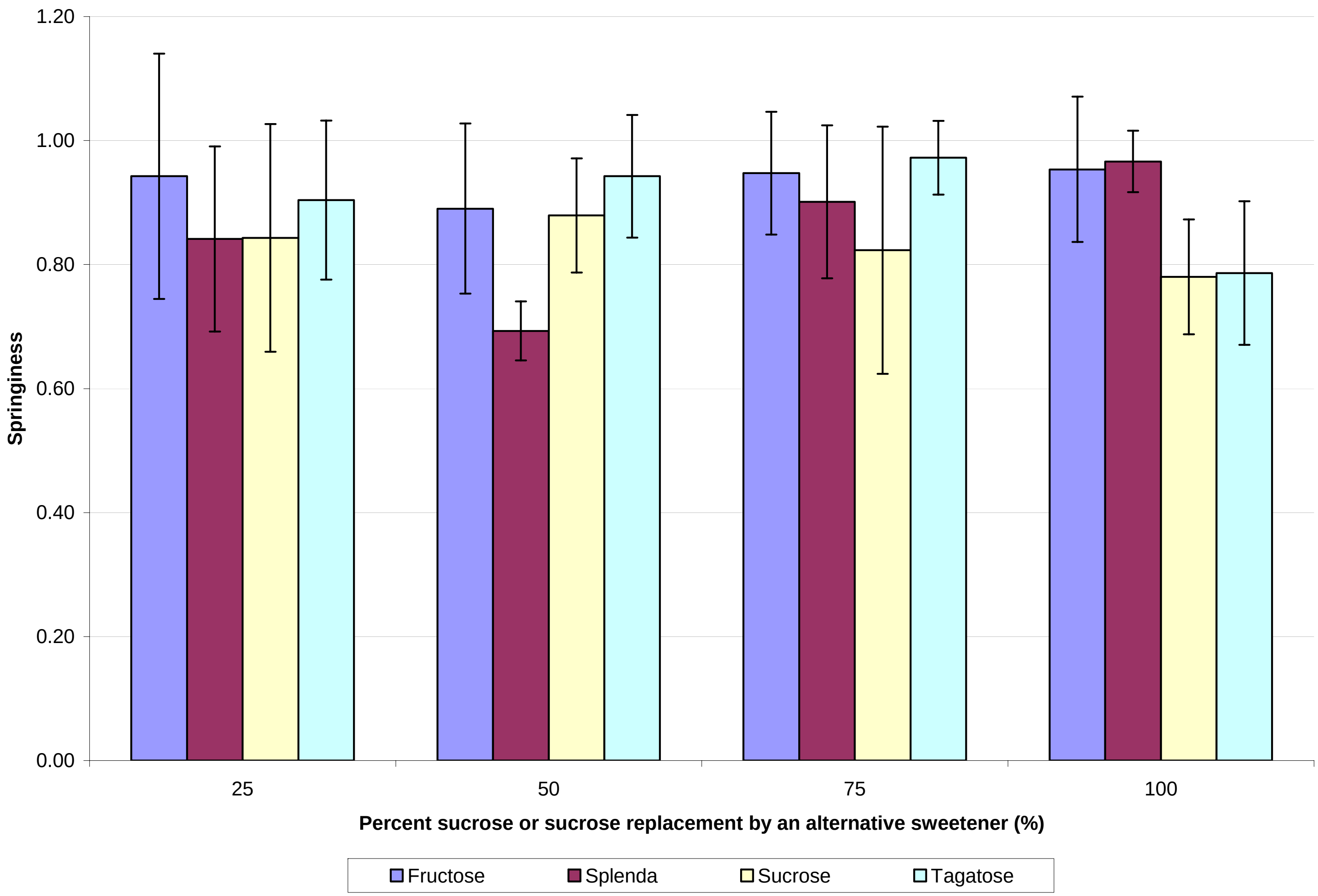


Springiness

Springiness is a measurement of how well the product springs back upon a second compression after it has been deformed during the first compression, similar to a second resilience, but it is represented as a ratio of the relationship to the first compression. Figure 4.5 shows graphically the variation in springiness of cookie dough made using the various sweeteners. Replacing sucrose with Splenda produced cookie dough with significantly greater springiness (0.97 ± 0.05) than when sucrose was used (0.78 ± 0.09). Cookie dough made with tagatose exhibited similar springiness values as compared to dough made with sucrose (0.79 ± 0.12 and 0.78 ± 0.09 respectively).

Generally, when sucrose was replaced with the other sweeteners, the springiness of the cookie dough increased. At 25% replacement, although this increase was observed, it was not statistically significant. When 50% of sucrose was replaced with tagatose, the increase in springiness became significant (0.78 ± 0.09 vs. 0.94 ± 0.10). At 75% replacement, only cookies dough made with tagatose yielded a significant increase. The other combinations of sucrose with the sweeteners produced cookie dough which did not differ significantly in springiness from each other. The exception was the cookie dough made by replacing 50% sucrose with Splenda, which had a lower springiness of 0.69 ± 0.05.

Figure 4.5 Mean springiness (± standard deviation) of cookie dough made using fructose, Splenda, sucrose and tagatose.



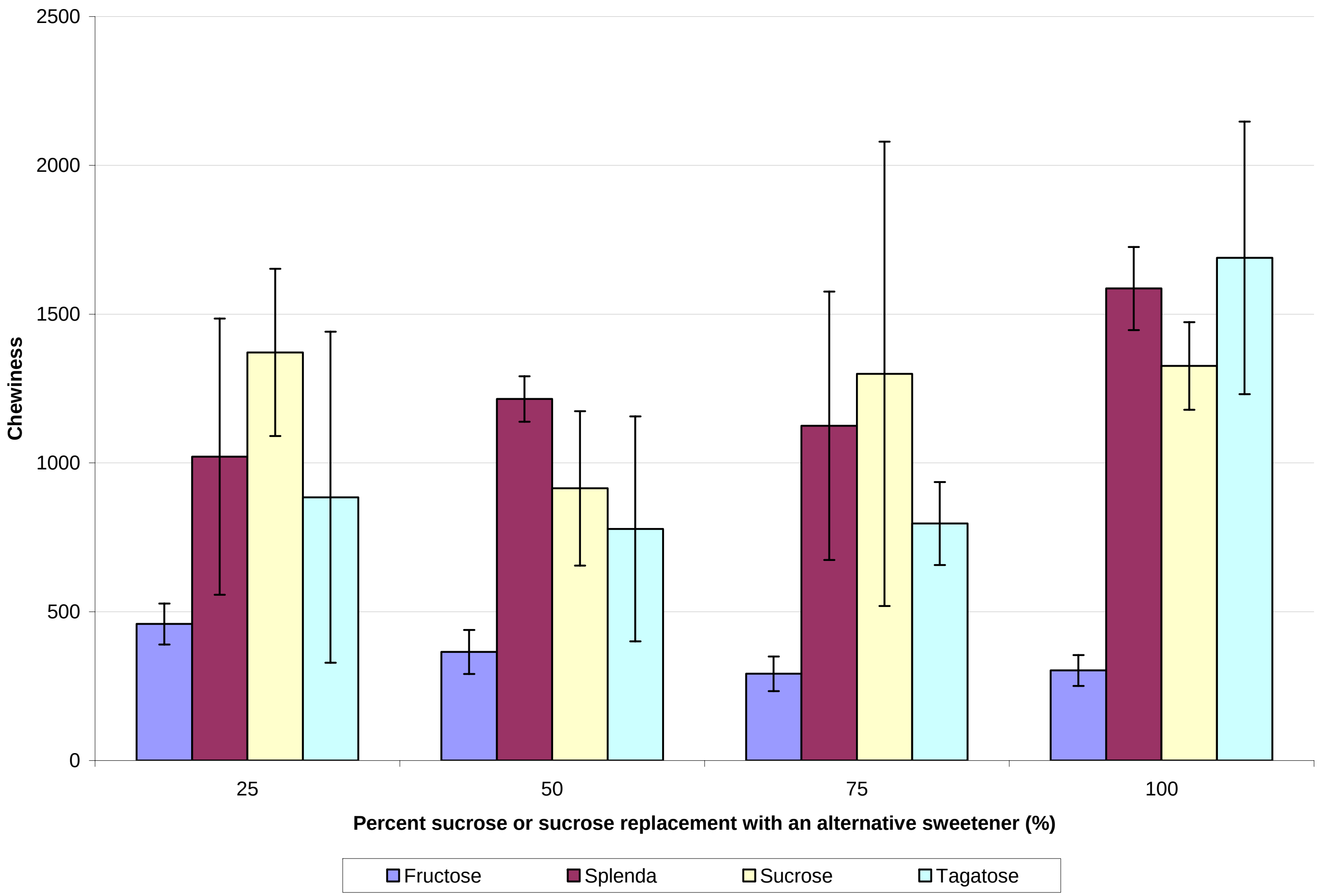
Chewiness

Chewiness is measured as the product of hardness, cohesiveness and springiness. It represents the force required to reduce a sample to a state ready for swallowing. Cookie dough made with tagatose showed the highest value for chewiness (1689 ± 458 g), followed by dough made with Splenda (1586 ± 139 g), 100% sucrose (1326 ± 147 g) and the lowest was dough made with fructose (303 ± 52 g) (Figure 4.6).

Cookie dough made with fructose and combinations of fructose with sucrose produced cookie dough with the lowest chewiness. Although cookie dough made with tagatose exhibited the greatest chewiness, when tagatose was combined with sucrose, the cookie dough produced was less chewy than when sucrose was used, in a similar trend to cookie dough hardness. Replacing 25% of sucrose with tagatose resulted in cookie dough which was less chewy ($p < 0.05$) (885 ± 556 and 1326 ± 147 g). Cookie dough made with Splenda had similar chewiness values to dough made with sucrose.

Cookie dough that exhibited greater hardness generally exhibited higher values of chewiness. Sugars affect chewiness in a manner similar to hardness. The high solubility of fructose leads to a softer and less chewy dough. The low levels of Splenda used resulted in chewiness values similar to dough made with only sucrose. Tagatose, being less soluble, produces cookie dough with higher chewiness values.

Figure 4.6 Mean chewiness (± standard deviation) of cookie dough made using fructose, Splenda, sucrose and tagatose.



Physical properties of the baked cookies

The physical properties of the baked cookie examined were color, force required to rupture the cookies, height, diameter and spread ratio (diameter/height). Figure 4.7 shows pictures taken of cookies baked with 100% sucrose, fructose, Splenda and tagatose.

Color

Color L, a, and b values of the samples are shown in Table 4.3. 'L' values are indicative of the lightness of samples. Lower L values indicate a darker surface color. The 'a' values indicate degree of redness or greenness. Positive values signify redness, while negative values indicate more greenness. The 'b' values indicate yellowness or blueness axis. Positive values represent yellow, while negative values represent blue.

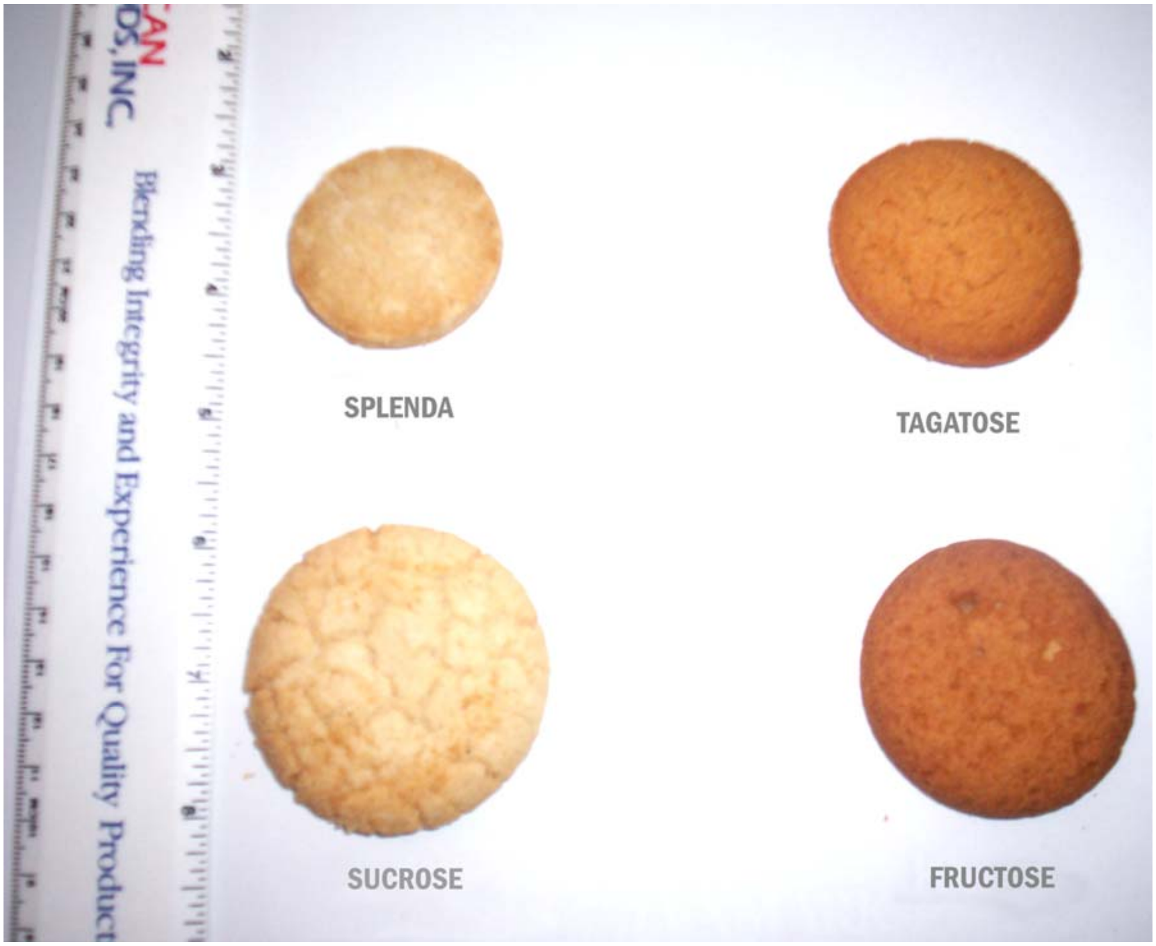


Figure 4.7 Picture of cookies baked with 100% Splenda, tagatose, sucrose and fructose (from top left to right).

Table 4.3 Mean color L, a, and b values of cookies made using sucrose, fructose, tagatose and Splenda.

Sweetener	Percent replacement of sucrose (%)	Color		
		L	a	b
Sucrose	n/a	58.90 ± 2.39^{a}	9.68 ± 1.03^{a}	29.96 ± 1.19^{a}
Fructose	25	43.23 ± 0.50^{b}	16.99 ± 0.54^{b}	25.79 ± 0.99^{b}
Splenda	25	62.29 ± 0.90^{a}	9.85 ± 0.31^{a}	29.21 ± 0.54^{a}
Tagatose	25	41.09 ± 0.41^{b}	15.83 ± 0.08^{b}	25.51 ± 0.11^{b}
Sucrose	n/a	58.90 ± 2.39^{a}	9.68 ± 1.03^{a}	29.96 ± 1.19^{a}
Fructose	50	42.05 ± 0.76^{b}	16.45 ± 0.31^{b}	27.92 ± 2.85$^{a\,b}$
Splenda	50	62.25 ± 2.28^{a}	9.67 ± 0.25^{a}	29.03 ± 0.33$^{a\,b}$
Tagatose	50	42.31 ± 0.37^{b}	16.04 ± 0.13^{b}	26.25 ± 0.08^{b}
Sucrose	n/a	58.90 ± 2.39^{a}	9.68 ± 1.03^{a}	29.96 ± 1.19^{a}
Fructose	75	42.34 ± 0.38^{b}	16.78 ± 0.04^{b}	27.66 ± 0.16$^{a\,b}$
Splenda	75	60.46 ± 0.44^{a}	8.06 ± 0.53^{c}	28.12 ± 0.41^{ab}
Tagatose	75	40.43 ± 0.86^{b}	16.52 ± 0.01^{b}	26.26 ± 0.05^{b}
Sucrose	n/a	58.90 ± 2.39^{a}	9.68 ± 1.03^{a}	29.96 ± 1.19^{a}
Fructose	100	41.63 ± 0.52^{b}	16.48 ± 0.22^{b}	26.67 ± 0.30^{b}
Splenda	100	63.60 ± 2.34^{c}	9.94 ± 0.12^{a}	28.55 ± 0.07^{a}
Tagatose	100	38.71 ± 1.53^{b}	16.75 ± 0.23^{b}	26.91 ± 0.05^{b}

Values are presented as mean ± std

$^{a\,b\,c}$ means with differing superscripts are significantly different within the same sugar concentration

n = 3

The mean L values for cookies made with 100% fructose and tagatose were 41.63 ± 0.52 and 38.71 ± 1.53 respectively, which were significantly lower ($p < 0.05$) than the mean value for cookies made with 100% sucrose (58.90 ± 2.39) and Splenda (63.60 ± 2.34). This is indicative of the participation of both fructose and tagatose in Maillard browning reactions, which involve reducing sugars, to produce darker, brown pigments. Sucrose and the sucralose in Splenda are not reducing sugars, and so do not participate directly in the Maillard reaction. However, sucrose can be hydrolyzed into its monosaccharide units, glucose and fructose, both of which are reducing sugars and able to participate in the Maillard reaction. This may account for the significant difference ($p < 0.05$) between the L values of cookies made with 100% sucrose and Splenda. As previously mentioned, Barndt and Jackson (1990) reported that Splenda did not appear to degrade after baking for 25 minutes at 180°C, thus its reducing sugar components are not released.

The 'a' values (which represents the degree of redness) for cookies made with 100% fructose and tagatose (16.48 ± 0.22 and 16.75 ± 0.23) were significantly greater ($p < 0.05$) than the values for sucrose and Splenda (9.68 ± 1.03 and 9.94 ± 0.12 respectively). Even when sucrose is combined with fructose or tagatose, this trend is also observed. When just 25% of sucrose is replaced with either of the two reducing sugars, their presence is significant enough to produce a darker cookie with significantly lower 'L' and greater 'a' values than cookies made with

100% sucrose. The L and a values for the reducing sugar blends were similar to values obtained for cookies made with 100% of the individual reducing sugars. It was expected that as the level of reducing sugar is reduced, the color would become lighter, and more similar to that of cookies made with 100% sucrose. This expected result was not observed.

The 'b' values (which indicates the degree of yellowness) for cookies made with 100% sucrose (29.96 ± 1.19) and Splenda (28.55 ± 0.07) were similar to each other, but were significantly greater ($p < 0.05$) than the values for cookies made with fructose (26.67 ± 0.30) and tagatose (26.91 ± 0.05). Cookies made with sucrose and Splenda were slightly more yellow than those made with fructose and tagatose.

Cookie Height

For the recipes baked with sucrose only, as the sucrose content decreases without being replaced with another sweetener, cookie height increases. When the sucrose concentration was 50% of the original amount, this increase became significant ($p < 0.05$) (Table 4.4 and 4.5) similar to observations by Manohar and Rao (1997). Gluten development contributes to an expansion in height of baked products, but cookies do not increase dramatically in height, because sugar preferentially attracts water over the gluten proteins. Therefore as the amount of sugar in the recipe decreases, the height of the cookies increases.

Table 4.4 Mean height, diameter, spread ratio (diameter/height) and snap force of cookies baked with sucrose, fructose, tagatose and Splenda.

Sweetener	Percent replacement of sucrose (%)	n†	Snap Force (g)	Height, H (mm)	Diameter, D (mm)	Spread, S (D/H)
Sucrose	100	24	1610 ± 175^{a}	11.50 ± 0.35^{a}	74.00 ± 0.75^{a}	6.44 ± 0.24^{a}
Fructose	25	12	1723 ± 157^{a}	9.80 ± 0.25^{b}	68.37 ± 0.65^{b}	6.98 ± 0.18^{b}
Splenda	25	12	1759 ± 571^{a}	11.14 ± 0.22^{a}	71.78 ± 0.67^{b}	6.45 ± 0.11^{a}
Tagatose	25	12	1747 ± 136^{a}	11.71 ± 0.36^{a}	71.67 ± 0.50^{b}	6.12 ± 0.20^{a}
Sucrose	100	24	1610 ± 175^{a}	11.50 ± 0.35^{a}	74.00 ± 0.75^{a}	6.44 ± 0.24^{a}
Fructose	50	12	1604 ± 150^{a}	10.38 ± 0.98^{b}	71.00 ± 0.87^{b}	6.90 ± 0.70^{a}
Splenda	50	12	1707 ± 88^{a}	12.58 ± 0.35^{c}	62.00 ± 0.43^{c}	4.93 ± 0.13^{b}
Tagatose	50	12	1751 ± 313^{a}	12.20 ± 0.54$^{a\,c}$	69.90 ± 0.66^{b}	5.74 ± 0.23^{c}
Sucrose	100	24	1610 ± 175^{ab}	11.50 ± 0.35^{a}	74.00 ± 0.75^{a}	6.44 ± 0.24^{a}
Fructose	75	9	1518 ± 15^{a}	12.22 ± 0.71^{a}	69.00 ± 1.22^{b}	5.66 ± 0.30^{b}
Splenda	75	12	1359 ± 109^{a}	13.56 ± 0.27^{b}	61.00 ± 0.66^{c}	4.50 ± 0.08^{c}
Tagatose	75	9	1911 ± 262^{b}	13.50 ± 0.66^{b}	67.06 ± 1.78^{b}	4.98 ± 0.24^{c}
Sucrose	100	24	1610 ± 175^{a}	11.50 ± 0.35^{a}	74.00 ± 0.75^{a}	6.44 ± 0.24^{a}
Fructose	100	12	701 ± 59^{b}	11.39 ± 1.02^{a}	69.50 ± 1.54^{b}	6.14 ± 0.42^{a}
Splenda	100	9	1302 ± 160^{a}	14.98 ± 0.04^{b}	54.33 ± 0.61^{c}	3.63 ± 0.04^{b}
Tagatose	100	12	2211 ± 135^{c}	14.00 ± 1.20^{b}	65.88 ± 3.29^{d}	4.75 ± 0.64^{c}

Results are presented as mean ± std

n† is for snap force. n = 9 for height diameter and spread.

$^{a\,b\,c}$ means with differing superscripts are significantly different ($p < 0.05$) from values of sugars at the same percentage and 100% sucrose

Table 4.5 Mean height, diameter, spread (diameter/height) and hardness of cookies baked with sucrose, fructose, tagatose and Splenda, as a function of sweetener concentration.

Sweetener	Percent replacement of sucrose (%)	n†	Snap Force (g)	Height, H (mm)	Diameter, D (mm)	Spread (D/H)
Sucrose	100	24	1610 ± 175[a]	11.50 ± 0.35[a]	74.00 ± 0.75[a]	6.44 ± 0.24[a]
Sucrose	75	12	1680 ± 365[a]	11.00 ± 0.00[a]	71.94 ± 0.98[a]	6.54 ± 0.09[a]
Sucrose	50	12	1415 ± 168[a]	12.83 ± 0.25[b]	65.22 ± 1.00[b]	5.08 ± 0.16[b]
Sucrose	25	12	1524 ± 213[a]	12.61 ± 1.89[b]	57.50 ± 2.00[c]	4.59 ± 0.46[b]
Fructose	100	12	701 ± 59[a]	11.39 ± 1.02[ac]	69.50 ± 1.54[a]	6.14 ± 0.42[a]
Fructose	75	9	1518 ± 15[b]	12.22 ± 0.71[a]	69.00 ± 1.22[a]	5.66 ± 0.30[a]
Fructose	50	12	1604 ± 150[b]	10.38 ± 0.98[bc]	71.00 ± 0.87[a]	6.90 ± 0.70[b]
Fructose	25	12	1723 ± 157[b]	9.80 ± 0.25[b]	68.37± 0.65[a]	6.98 ± 0.18[b]
Splenda	100	9	1302 ± 160[a]	14.98 ± 0.04[a]	54.33 ± 0.61[a]	3.63 ± 0.04[a]
Splenda	75	12	1359 ± 109[ab]	13.56 ± 0.27[b]	61.00 ± 0.66[b]	4.50 ± 0.08[b]
Splenda	50	12	1707 ± 88[bc]	12.58 ± 0.35[b]	62.00 ± 0.43[b]	4.93 ± 0.13[b]
Splenda	25	12	1759 ± 571[c]	11.14 ± 0.22[c]	71.78 ± 0.67[c]	6.45 ± 0.11[c]
Tagatose	100	12	2211 ± 135[a]	14.00 ± 1.20[a]	65.88 ± 3.29[a]	4.75 ± 0.64[a]
Tagatose	75	9	1911 ± 262[ab]	13.50 ± 0.66[a]	67.06 ± 1.78[a b]	4.98 ± 0.24[a]
Tagatose	50	12	1751 ± 313[b]	12.20 ± 0.54[b]	69.90 ± 0.66[a b]	5.74 ± 0.23[b]
Tagatose	25	12	1747 ± 136[b]	11.71 ± 0.36[b]	71.67 ± 0.50[b]	6.12 ± 0.20[b]

Values are presented as mean ± std

n† is for snap force. n = 9 for height diameter and spread.

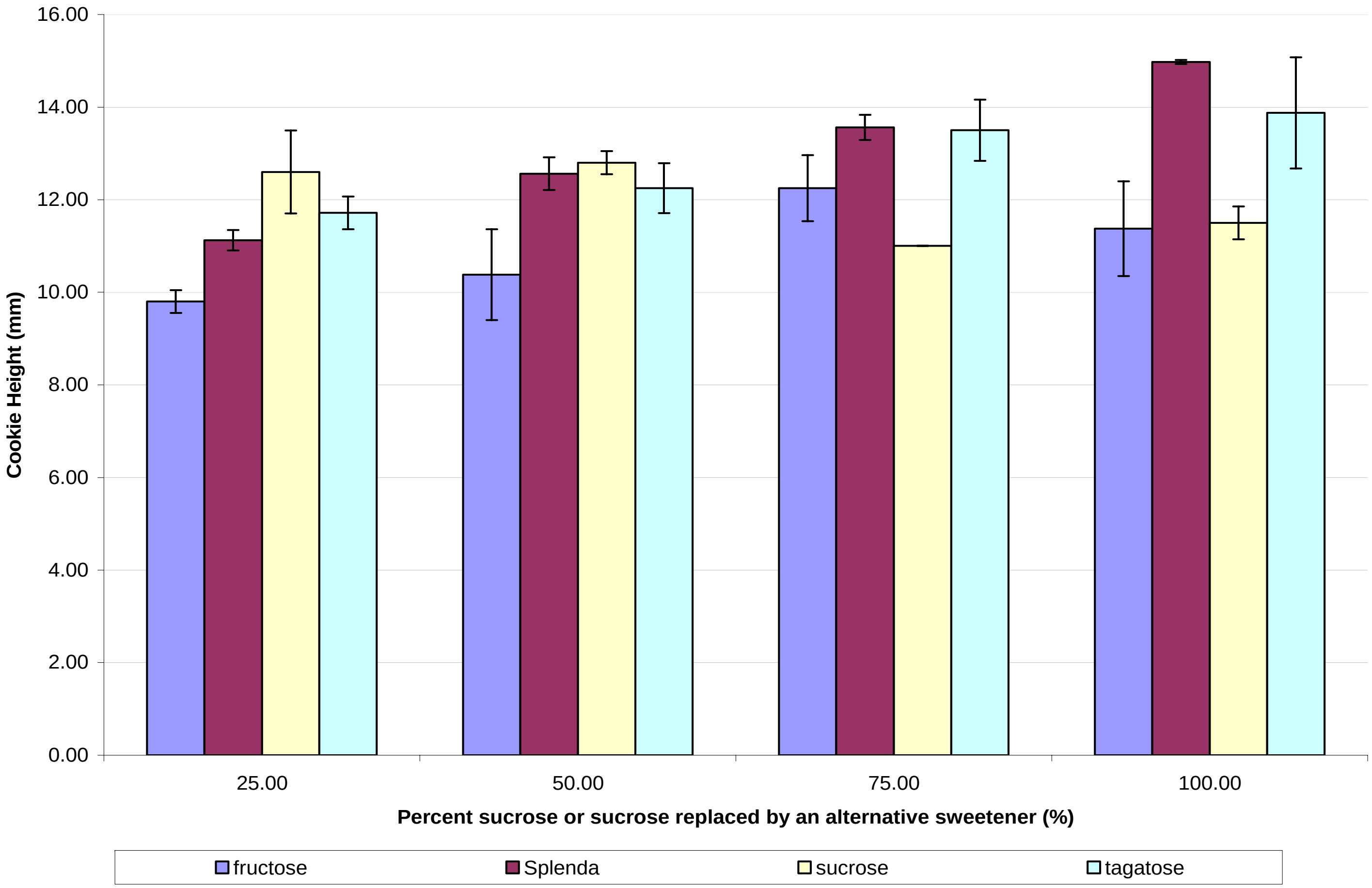
[a b c] means with differing superscripts are significantly different ($p < 0.05$) within the same sugar type

This trend is also observed in the cookies baked with Splenda and sucrose combinations. Since Splenda is a high intensity sweetener, much less is required to impart sweetness attributes to the product. Therefore, as sucrose is increasingly replaced by Splenda, the total amount of sucrose in the recipe decreases, resulting in more gluten development and an increase in cookie height, from 11.13 ± 0.35 mm with 25% of sucrose replaced with Splenda, to 14.98 ± 0.05 mm with 100% replacement of sucrose with Splenda (Figure 4.8).

Fructose also has a high attraction for water, so cookies baked with 100% fructose are similar in height to cookies made with 100% sucrose (11.39 ± 1.02 and 11.50 ±0.35 mm). When fructose and sucrose were combined, there was a decrease in cookie height. The combination of 25% fructose with 75% sucrose produced cookies with the least height (9.80 ± 0.25).

When cookies are baked using 100% tagatose, the height of the cookies increased significantly from an average of 11.50 ± 0.35 mm for 100% sucrose to 13.88 ± 1.31 mm for tagatose. As mentioned before, tagatose is much less hygroscopic than sucrose (62% w/w at 30°C compared to 238.1% w/w at 40°C). Therefore, it leaves more water available for gluten development, and allows for an increased height of the cookies.

Figure 4.8 Mean height (± standard deviation) of cookies baked using fructose, Splenda, sucrose and tagatose.

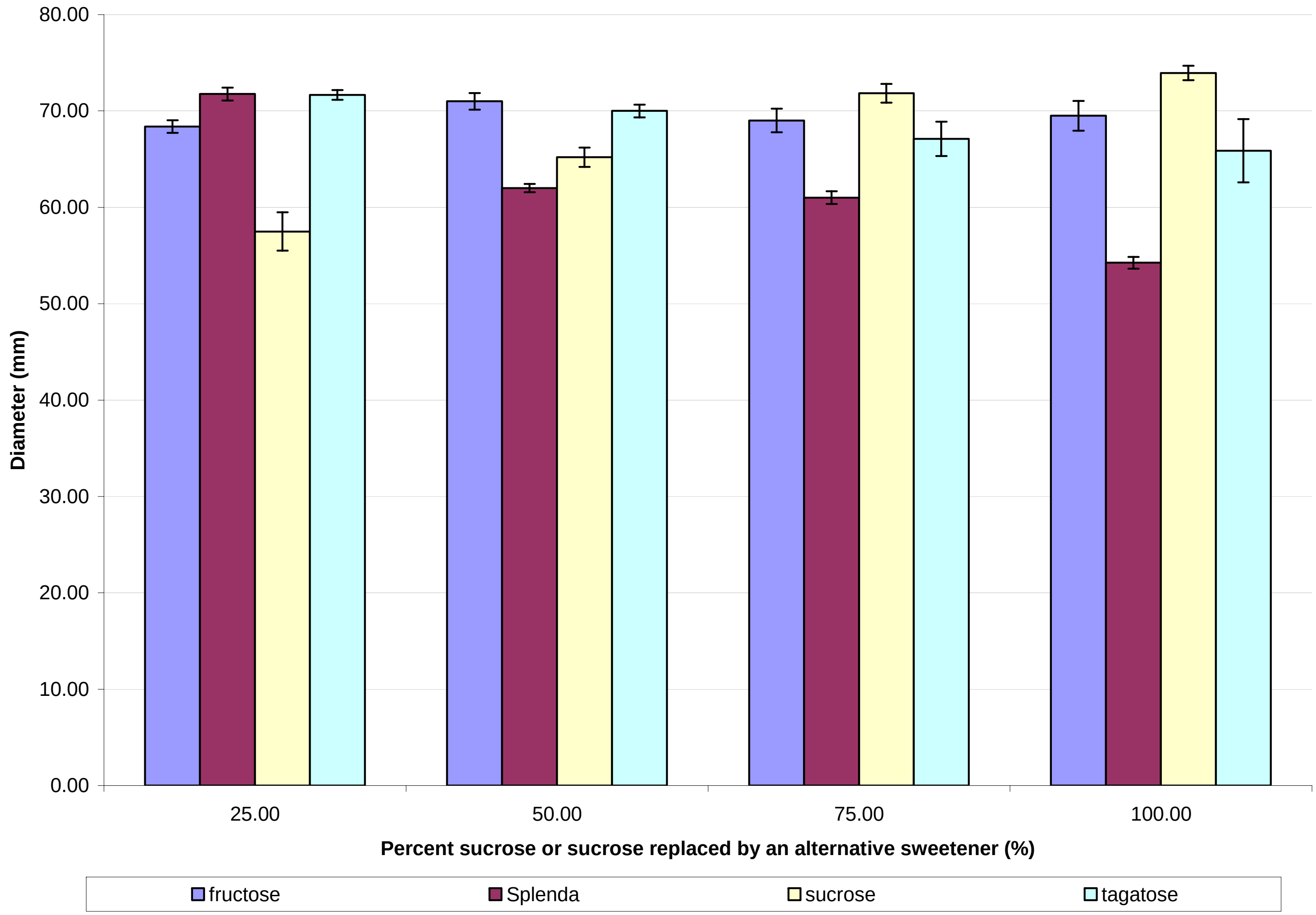


Cookie Diameter

As sucrose was reduced (without replacement), the diameter of the cookies decreased significantly ($p < 0.05$), from 74.00 ± 0.75 mm for 100% sucrose to 57.50 ± 2.00 mm for 25% sucrose (Figure 4.9). Since sucrose is not completely dissolved prior to baking, the undissolved crystalline portion dissolves into syrup during baking, which causes spreading and results in the increase in diameter observed. Hoseney and Rogers (1994) reported that increase in diameter is controlled by the rate at which the dough flows and by the time at which it stops flowing. Cookies baked with 100% fructose were significantly smaller in diameter ($p < 0.05$) than cookies baked with 100% sucrose (69.50 ± 1.54 and 74.00 ± 0.75 mm, respectively). This may be because fructose dissolves more completely prior to baking, so additional dissolution does not occur during baking, and therefore its ability to spread is reduced. Zoulias and others (2000) and Doescher and others (1987) also found that use of fructose restricts cookie spread more than sucrose.

Tagatose-containing cookies were significantly smaller in diameter than cookies made with fructose (65.88 ± 3.29 and 69.50 ± 1.54 mm, respectively). This may be because tagatose, being less soluble, maintains its undissolved nature longer during baking, which restricts the flow of the dough.

Figure 4.9 Mean diameter (± standard deviation) of cookies baked using fructose, Splenda, sucrose and tagatose.



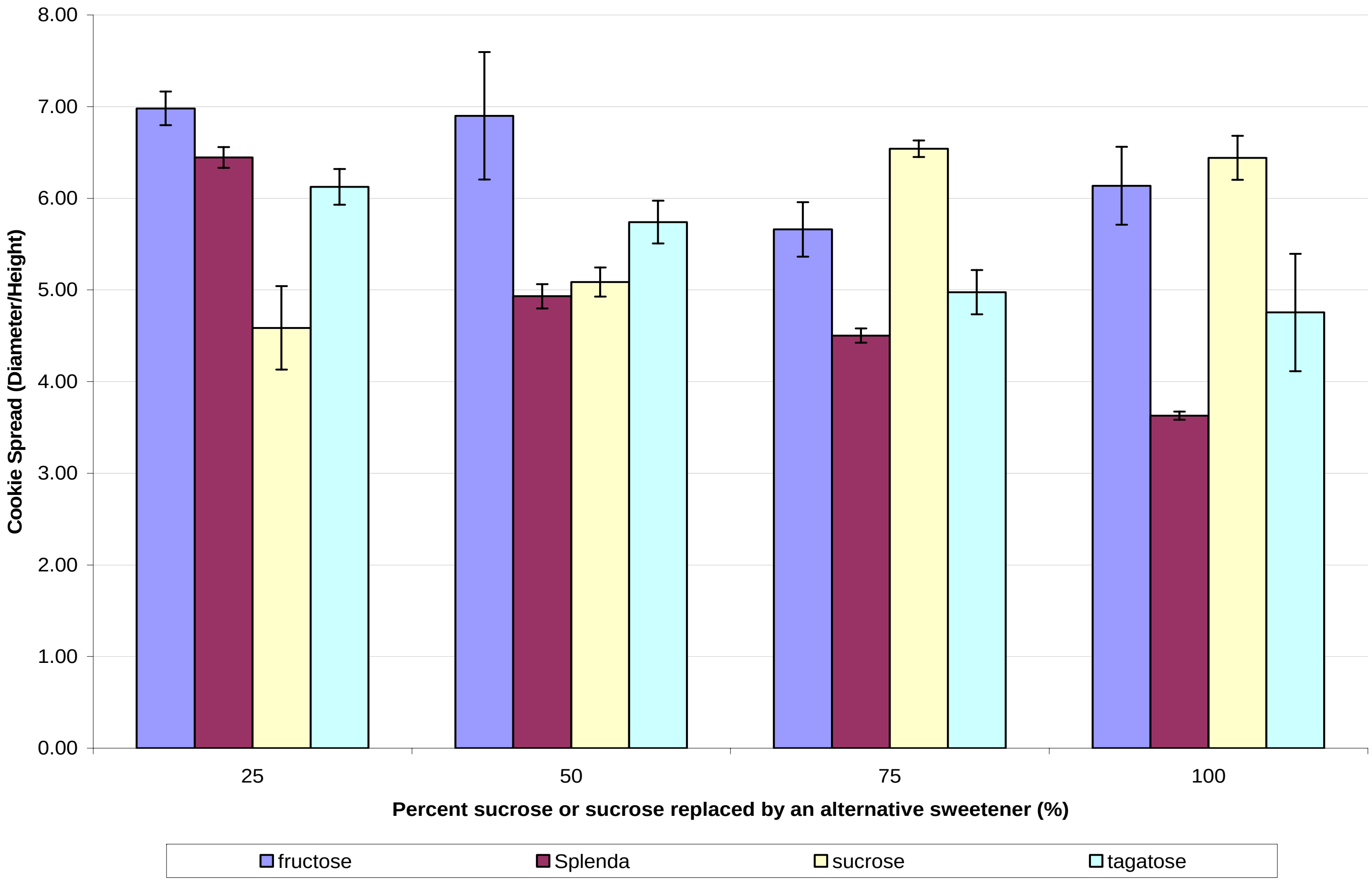
Although cookies baked with 100% Splenda had the greatest height (14.98 ± 0.05 mm), they had the smallest diameter (54.25 ± 0.65 mm), which was statistically smaller than cookies baked with the other sweeteners ($p < 0.05$). This can be attributed to the loss of sugars as less Splenda is used. The lack of sugars to dissolve during baking restricts the ability of cookies baked with 100% Splenda to spread.

Combinations of sucrose with the other sweeteners produced cookies with smaller diameters than cookies made with 100% sucrose. Replacement of 25% sucrose with any sweetener was enough to make the cookie diameter significantly smaller ($p < 0.05$).

Cookie Spread Ratio

Cookie spread represents a ratio of diameter to height. Generally, the spread ratio increases as the amount of sucrose added (without any additional sweetener) increases, due to a decrease in height and an increase in diameter (Figure 4.10). Kulp and others (1991) suggested that for sucrose, because all of the sugar is not dissolved in the creaming stage, sugar syrup is formed in the cookies during baking, leading to increase diameter. There is also a decrease in height due to inhibition of gluten development by incorporating more sugar. Therefore, the more sucrose incorporated into the cookie recipe, the greater the spread ratio (Table 4.5).

Figure 4.10 Mean spread (± standard deviation) of cookies baked using sucrose, fructose, Splenda and tagatose.



When sucrose was used in combination with Splenda, a decrease in cookie diameter and an increase height was observed, resulting in a decrease in spread ratio. Cookies baked with tagatose and Splenda produced cookies with significantly lower spread ratios of 4.75 ± 0.64 and 3.63 ± 0.04 respectively, than cookies made using 100% sucrose (6.44 ± 0.24) and fructose (6.14 ± 0.42).

Fructose dissolves during dough formation more than sucrose. Therefore, there is much less syrup formation during baking resulting in a smaller increase in diameter than with sucrose. Fructose also has a high affinity for water, so using fructose alone, or in combination with sucrose, also led to a decrease in cookie height, due to less gluten development. Depending on which property prevailed when sucrose and fructose were combined, some spread ratios proved to be lower, while some were higher.

Baking with tagatose also resulted in cookies with a decreased diameter, due to the lower solubility of this sweetener. Because tagatose does not have as much affinity for water as sucrose or fructose, the cookie height increased. Thus a lower spread ratio for cookies baked with tagatose resulted as compared to those baked with sucrose and fructose.

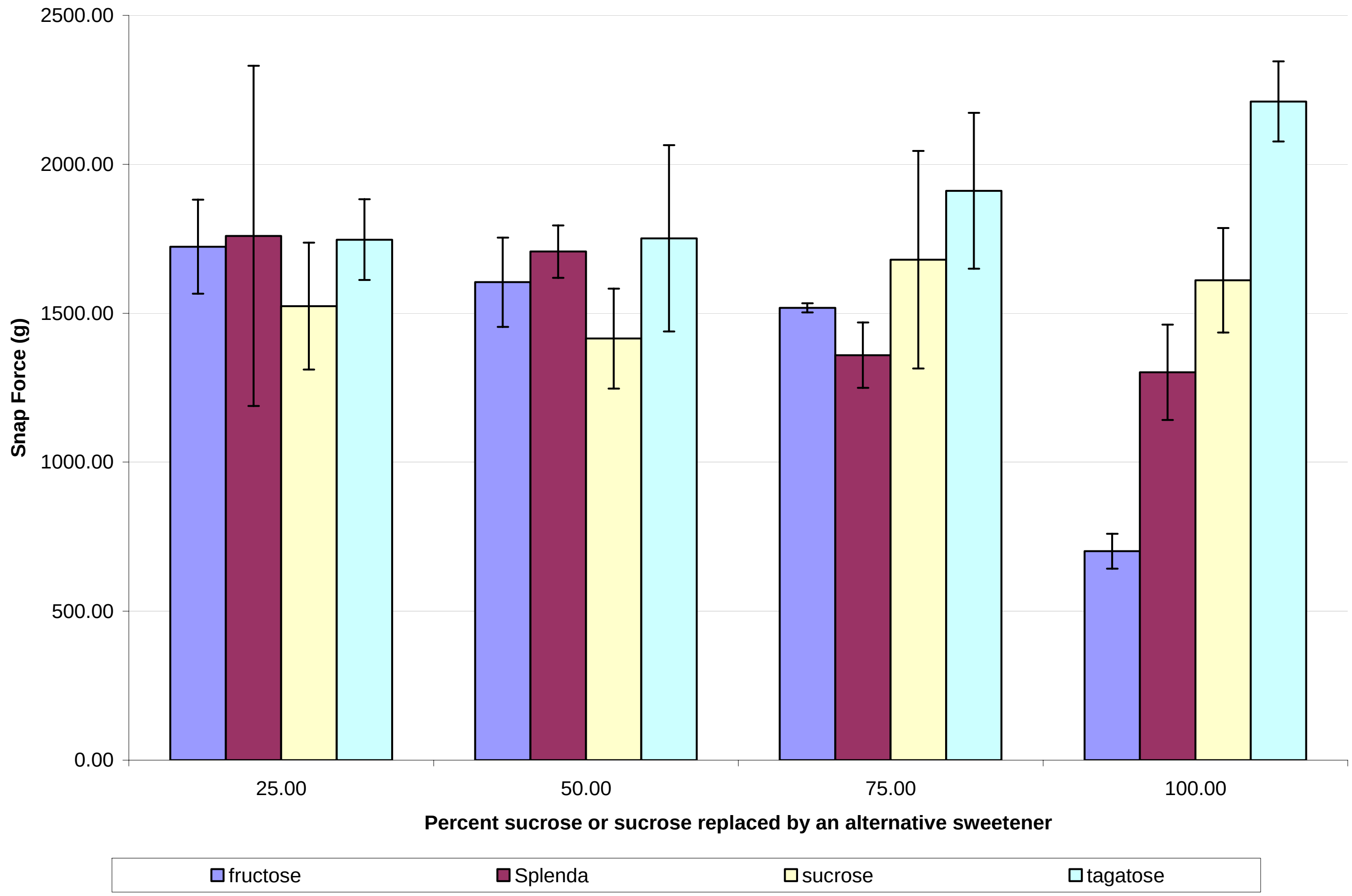
Cookie Snap Force

Snap force represents the force required to rupture the cookies, which is indicative of cookie hardness. Cookies produced from 100% sucrose, fructose, Splenda and tagatose, exhibited a similar trend in snap force, as that observed for the cookie dough hardness (Figure 4.11). Cookies made with 100% tagatose were significantly harder ($p < 0.05$) than cookies made with sucrose (2211 ± 135 g and 1610 ± 175 g, respectively). Cookies made with 100% fructose were significantly less hard ($p < 0.05$) than cookies made with sucrose (701 ± 59 g and 1610 ± 175 g, respectively). Replacing sucrose with Splenda produced a cookie with similar hardness (1302 ± 160 g and 1610 ± 175 g, respectively). This trend is similar to that observed with cookie dough hardness.

As mentioned before, the hardness of cookie (dough and baked product) results from the development of a gluten network to form the cookie structure. Gluten must interact with water molecules to promote development of the network, but sugars interfere with this by preferentially attracting water. Fructose, being the most soluble of the sugars used, has a very high affinity for water, and thus interferes the most with gluten development, leading to a softer cookie. Sucrose is next in solubility, followed by tagatose. Since only a small amount of Splenda is used to replace sucrose, it does not have a significant effect on hardness. When sucrose is combined with the other sweeteners, the hardness of the cookies produced were not significantly different from that of cookies made with 100% sucrose.

After the baked cookie cools, sugars may crystallize which will also contribute to cookie hardness. Fructose, the most soluble sugar, had the least crystallization and softest cookie. Tagatose, being the least soluble, will crystallize to a larger extent and yield the hardest cookie. The hardness of the sucrose-containing cookies is between that of tagatose and fructose,

Figure 4.11 Mean snap force (± standard deviation) of cookies baked using fructose, Splenda, sucrose and tagatose.



Sensory Evaluation

Fifty-three participants were recruited for the consumer acceptability study of cookies baked using 100% tagatose, 100% sucrose and a 50-50 combination of tagatose and sucrose. A nine point hedonic scale (Appendix A), which ranged from dislike extremely to like extremely, was used to evaluate acceptability of color, sweetness, texture, and the overall acceptability of the cookies. Table 4.6 shows the average result for each of the examined parameters.

Table 4.6 Average rating assigned for consumer acceptance rating of cookies made using tagatose and sucrose.

Sweetener	Color	Sweetness	Texture	Overall
100% sucrose	6.13 ± 1.63^{a}	6.23 ± 1.81^{a}	5.42 ± 2.12^{a}	6.17 ± 1.82^{a}
50% tagatose-sucrose	5.89 ± 1.71^{a}	5.28 ± 1.85^{b}	5.51 ± 1.92^{a}	5.40 ± 1.99^{ab}
100% tagatose	6.85 ± 1.08^{b}	4.79 ± 1.92^{b}	6.02 ± 1.88^{a}	5.17 ± 2.02^{b}

Values are presented as mean ± std
n=53
1= dislike extremely 2= dislike very much 3= dislike moderately 4 = dislike slightly 5 = neither like nor dislike 6 = like slightly 7= like moderately 8= like very much 9= like extremely
$^{a\ b}$ different superscripts indicate a significant difference ($p < 0.05$) among results in each column

For the various cookies, the panelists reported the highest acceptability of sweetness to be that of sucrose, which on average was rated ‘like slightly.’ This was significantly greater than the rating for 100% and 50% tagatose, which were rated ‘neither like nor dislike’ on average. These results indicate that consumers may be able to perceive a difference in the sweetness levels of cookies baked with tagatose instead of sucrose. Tagatose imparts a dark brown color to cookies baked with it, as indicated in previous sections. The color imparted to the cookies was rated as 'like moderately' by the panelists, which was significantly greater ($p < 0.05$) than the rating for cookies baked with sucrose and the 50-50 tagatose/sucrose combination, both of which were rated 'like slightly.' The cookie with the highest overall rating was prepared with 100% sucrose, which the panelists on average rated 'like slightly,' but the overall rating for cookies baked with 50% tagatose was not significantly different from those containing only sucrose. The overall rating for cookies made with 100% tagatose was significantly lower ($p < 0.05$) than that for 100% sucrose, with an average rating of 'neither like nor dislike.' The results were significantly correlated with the ratings for sweetness ($r^2 = 0.88$). This result indicates that consumer perception of sweetness is important in determining the overall acceptability of the cookie.

The ratings of the cookies were lower than expected, but that may be due to the use of a very basic recipe. A simple basic recipe is necessary when measuring various physical properties by instrumental methods, but the expectations of participants may be that of a more commercial grade product. This may have contributed to an overall lower rating of all the cookies.

CHAPTER 5

CONCLUSION

Although tagatose and fructose have a similar chemical structure, with the only difference being the rotation of one of the hydroxyl groups, they impart different properties on the hardness of the cookie. Replacing sucrose with tagatose results in a significantly harder dough and cookie, but when fructose is used, a significantly softer dough and cookie are obtained. Both types of sugars produced baked cookies with decreased diameter and a darker color when compared to 100% sucrose. Cookies made from Splenda showed a similar color, and hardness to sucrose, but greater height and decreased diameter. Although fructose and tagatose produced a significantly browner cookie, a greater percentage of sensory panelists actually preferred this color, and the panelists did not dislike the sweetness of the cookies, although the average rating was 'neither like nor dislike.' When cookies were made from a combination with sucrose and the sweeteners examined, the results of the analysis were not always predictable. However, these results show that an acceptable cookie can be made by replacing at least some of sucrose with tagatose.

Ultimately, knowledge of the effects of replacing or combining sucrose with alternative sweeteners on the properties of cookies is invaluable to manufacturers of these products so that these properties can be manipulated to produce different types of cookies for consumers.

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APPENDIX A

CONSUMER ACCEPTABILITY QUESTIONNAIRE & SENSORY EVALUATION

INFORMATION SHEET
for Research Study Entitled
Sensory characteristics of D-Tagatose and Splenda as sugar replacers in cookies

You are invited to participate in a research study to evaluate the acceptability of D-Tagatose and Splenda as sucrose substitutes in cookies by examining the acceptability of sugar cookies baked with these sweeteners. This study is being conducted by Tanya Taylor, under the supervision of Dr. Leonard Bell, of the Department of Nutrition and Food Science.

In order to participate, you need to be at least 19 years of age but not older than 60 years, and be of good health. If you decide to participate, we require 10 minutes of your time, during which you will taste the coded cookie samples provided to you and indicate your answers to the questions on the provided forms. There are no risks or discomforts associated with ingesting these cookies. No identifying information will be collected during this study. The information collected through your participation may be used to fulfill an educational requirement for a PhD in Nutrition and Food Science at Auburn University, and published in a professional journal, and/or presented at a professional meeting. Participants may withdraw from participation at any time, without penalty. Your decision whether or not to participate will not jeopardize your future relations with Auburn University or the Department of Nutrition and Food Science.

If you have any questions we invite you to ask them now. If you have questions later, contact Tanya Taylor at taylotp@auburn.edu, or Dr. Leonard Bell at bellleo@auburn.edu, at the Department of Nutrition and Food Science, Auburn University, 334-844-4261. We will be happy to answer them. For more information regarding your rights as a research participant you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu .

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

____
Investigator's signature Date

____
Co-investigator's signature Date

Instructions:

1. Check the box next to the option that best indicates your age range.

☐ 19 – 25 ☐ 26 - 35 ☐ 36 – 45 ☐ 45 - 60

2. Check the box next to the option that best describes your gender.

☐ male ☐ female

3. Check the box next to the option that best represents how likely are you to CONSUME reduced sugar, sugar free or low carb products:

- ☐ Every time I was able to.
- ☐ Most of the time that I was able to.
- ☐ Occasionally.
- ☐ I would consume them if I saw it but would not go out of my way to obtain any.
- ☐ I don't like cookies but may eat it on occasion.
- ☐ I would consume them only if there were no other choices.

4. Check the box next to the option that best indicates how likely you are to CONSUME cookies:

- ☐ Every time I was able to.
- ☐ Most of the time that I was able to.
- ☐ Occasionally.
- ☐ I would consume them if I saw it but would not go out of my way to obtain any.
- ☐ I don't like cookies but may eat it on occasion.
- ☐ I would consume them only if there were no other choices.

Sample Code: ______________

* Record the sample code in the space above
* Please rinse your mouth with water before starting.
* Taste the sample and check the box which best describes your opinion of the cookie.

1. Check the box that best describes how well you like the **color** of the cookie.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

2. Check the box that best describes how well you like the **sweetness** of the cookie.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

3. Check the box that best describes how well you like the **texture** of the cookie.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

4. Check the box that best describes how well you like the cookie **overall**.

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

APPENDIX B

RAW DATA FOR COOKIES

Table B.1 Hunter Color L, a, b values for cookies made using sucrose and combinations of sucrose with tagatose, fructose and Splenda

Sweetener	Percent replacement of sucrose (%)	Color Values			
		replicate	L	a	b
sucrose	25	1	63.14	7.11	27.77
sucrose	25	2	60.55	8.56	29.30
sucrose	25	3	60.17	8.23	28.31
sucrose	50	1	63.56	8.57	29.34
sucrose	50	2	61.23	10.38	30.95
sucrose	50	3	61.95	8.58	28.59
sucrose	75	1	61.99	9.98	30.58
sucrose	75	2	64.77	9.37	30.53
sucrose	75	3	60.66	10.55	31.26
sucrose	100	1	61.38	8.76	29.31
sucrose	100	2	56.62	9.49	29.23
sucrose	100	3	58.69	10.80	31.33
tagatose	25	1	40.77	15.91	25.60
tagatose	25	2	40.94	15.76	25.39
tagatose	25	3	41.55	15.82	25.54
tagatose	50	1	42.22	16.18	26.34
tagatose	50	2	41.99	15.99	26.19
tagatose	50	3	42.71	15.94	26.23
tagatose	75	1	40.01	16.52	26.26
tagatose	75	2	41.42	16.52	26.31
tagatose	75	3	39.87	16.53	26.22
tagatose	100	1	39.99	16.73	26.95
tagatose	100	2	39.13	16.99	26.92
tagatose	100	3	37.01	16.53	26.85
fructose	25	1	42.77	17.51	26.79
fructose	25	2	43.17	16.44	24.81
fructose	25	3	43.76	17.01	25.77
fructose	50	1	41.26	16.77	31.21
fructose	50	2	42.77	16.43	26.29
fructose	50	3	42.13	16.15	26.25
fructose	75	1	42.23	16.75	27.61
fructose	75	2	42.03	16.78	27.53
fructose	75	3	42.76	16.82	27.83
fructose	100	1	42.11	16.23	26.67
fructose	100	2	41.08	16.58	26.38
fructose	100	3	41.70	16.64	26.97
Splenda	25	1	61.39	9.99	29.23
Splenda	25	2	62.29	9.75	29.27
Splenda	25	3	63.18	9.81	29.13

Table B.1 continued …

Sweetener	Percent replacement of sucrose (%)	Color Values			
		replicate	L	a	b
Splenda	50	1	63.94	9.69	29.23
Splenda	50	2	60.35	10.19	29.30
Splenda	50	3	64.57	9.13	28.55
Splenda	75	1	60.97	7.88	28.02
Splenda	75	2	60.23	8.35	28.49
Splenda	75	3	60.18	7.95	27.86
Splenda	100	1	61.10	10.21	27.96
Splenda	100	2	65.73	9.60	29.01
Splenda	100	3	63.96	10.01	28.67

n = 48

Table B.2 Snap force of cookies made using sucrose and combinations of sucrose with tagatose, fructose and Splenda.

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Snap Force (g)	Daily Average Snap Force (g)	Standard Deviation for Daily Mean
1	sucrose	25	1	1445.10		
1	sucrose	25	2	1602.70		
1	sucrose	25	3	1455.60	1501.13	88.12
2	sucrose	25	1	1228.10		
2	sucrose	25	2	1216.50		
2	sucrose	25	3	1253.30	1232.63	18.81
3	sucrose	25	1	1739.30		
3	sucrose	25	2	1655.60		
3	sucrose	25	3	1730.30	1708.40	45.95
4	sucrose	25	1	1735.00		
4	sucrose	25	2	1701.00	1718.00	24.04
1	sucrose	50	1	1616.70		
1	sucrose	50	2	1514.20		
1	sucrose	50	3	1572.70	1567.87	51.42
2	sucrose	50	1	1626.20		
2	sucrose	50	2	1606.70		
2	sucrose	50	3	1529.40	1587.43	51.20
3	sucrose	50	1	1234.00		
3	sucrose	50	2	1374.20		
3	sucrose	50	3	1181.30	1263.17	99.70

Table B.2 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Snap Force (g)	Daily Average Snap Force (g)	Standard Deviation for Daily Mean
4	sucrose	50	1	1361.20		
4	sucrose	50	2	1349.40		
4	sucrose	50	3	1133.20	1281.27	128.37
5	sucrose	50	1	1354.90		
5	sucrose	50	2	1235.70		
5	sucrose	50	3	1533.20	1374.60	149.73
1	sucrose	75	1	1332.60		
1	sucrose	75	2	1142.20		
1	sucrose	75	3	1170.10	1214.97	102.82
2	sucrose	75	1	1508.80		
2	sucrose	75	2	1605.80		
2	sucrose	75	3	1458.70	1524.43	74.79
3	sucrose	75	1	2198.30		
3	sucrose	75	2	2180.20		
3	sucrose	75	3	1995.50	2124.67	112.23
4	sucrose	75	1	1805.10		
4	sucrose	75	2	1874.00		
4	sucrose	75	3	1887.50	1855.53	44.20
1	sucrose	100	1	1896.60		
1	sucrose	100	2	1493.50		
1	sucrose	100	3	1697.70	1695.93	201.56
2	sucrose	100	1	1321.70		
2	sucrose	100	2	2117.70		
2	sucrose	100	3	1460.80	1633.40	425.14
3	sucrose	100	1	1709.10		
3	sucrose	100	2	1688.10		
3	sucrose	100	3	1713.10	1703.43	13.43
4	sucrose	100	1	1583.40		
4	sucrose	100	2	1570.80		
4	sucrose	100	3	1658.50	1604.23	47.42
5	sucrose	100	1	1621.30		
5	sucrose	100	2	1551.00		
5	sucrose	100	3	1610.70	1594.33	37.90
6	sucrose	100	1	1750.30		
6	sucrose	100	2	1663.80		
6	sucrose	100	3	1549.40	1654.50	100.77
7	sucrose	100	1	1568.50		
7	sucrose	100	2	1605.40		
7	sucrose	100	3	1659.20	1611.03	45.61
8	sucrose	100	1	1419.40		
8	sucrose	100	2	1476.10		
8	sucrose	100	3	1263.90	1386.47	109.87

Table B.2 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Snap Force (g)	Daily Average Snap Force (g)	Standard Deviation for Daily Mean
1	tagatose	100	1	2322.30		
1	tagatose	100	2	2104.60		
1	tagatose	100	3	2088.40	2171.77	130.62
2	tagatose	100	1	2287.50		
2	tagatose	100	2	2014.70		
2	tagatose	100	3	2122.40	2141.53	137.40
3	tagatose	100	1	2206.50		
3	tagatose	100	2	2361.10		
3	tagatose	100	3	2389.90	2319.17	98.63
1	tagatose	75	1	1799.90		
1	tagatose	75	2	1775.50		
1	tagatose	75	3	1773.30	1782.90	14.76
2	tagatose	75	1	2287.60		
2	tagatose	75	2	2165.00		
2	tagatose	75	3	2266.80	2239.80	65.61
3	tagatose	75	1	1857.70		
3	tagatose	75	2	1710.40		
3	tagatose	75	3	1561.40	1709.83	148.15
1	tagatose	50	1	1845.60		
1	tagatose	50	2	1768.10		
1	tagatose	50	3	1632.90	1748.87	107.65
2	tagatose	50	1	1606.10		
2	tagatose	50	2	2013.70		
2	tagatose	50	3	2515.50	2045.10	455.51
3	tagatose	50	1	1598.80		
3	tagatose	50	2	1522.70		
3	tagatose	50	3	1307.00	1476.17	151.36
4	tagatose	50	1	1685.40		
4	tagatose	50	2	1534.40		
4	tagatose	50	3	1985.90	1735.23	229.84
1	tagatose	25	1	1558.90		
1	tagatose	25	2	1696.70		
1	tagatose	25	3	1857.90	1704.50	149.65
2	tagatose	25	1	1746.40		
2	tagatose	25	2	1877.50		
2	tagatose	25	3	1645.30	1756.40	116.42
3	tagatose	25	1	1788.40		
3	tagatose	25	2	1956.20		
3	tagatose	25	3	1592.40	1779.00	182.08

Table B.2 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Snap Force (g)	Daily Average Snap Force (g)	Standard Deviation for Daily Mean
1	Splenda	100	1	1385.30		
1	Splenda	100	2	1333.40		
1	Splenda	100	3	1495.10	1404.60	82.56
2	Splenda	100	1	1422.10		
2	Splenda	100	2	1431.40		
2	Splenda	100	3	1349.50	1401.00	44.84
3	Splenda	100	1	1082.20		
3	Splenda	100	2	1065.90		
3	Splenda	100	3	1153.70	1100.60	46.70
1	Splenda	75	1	1391.70		
1	Splenda	75	2	1240.60		
1	Splenda	75	3	1263.80	1298.70	81.37
2	Splenda	75	1	1371.50		
2	Splenda	75	2	1366.00		
2	Splenda	75	3	1591.20	1442.90	128.46
3	Splenda	75	1	1271.67		
3	Splenda	75	2	1298.91		
3	Splenda	75	3	1438.37	1336.32	89.42
1	Splenda	50	1	1669.10		
1	Splenda	50	2	1708.90		
1	Splenda	50	3	1660.70	1679.57	25.75
2	Splenda	50	1	1721.60		
2	Splenda	50	2	1657.70		
2	Splenda	50	3	1619.90	1666.40	51.41
3	Splenda	50	1	1631.50		
3	Splenda	50	2	1801.90		
3	Splenda	50	3	1890.70	1774.70	131.72
1	Splenda	25	1	1462.50		
1	Splenda	25	2	1286.40		
1	Splenda	25	3	1303.20	1350.70	97.19
2	Splenda	25	1	1314.90		
2	Splenda	25	2	1727.70		
2	Splenda	25	3	1273.40	1438.67	251.17
3	Splenda	25	1	2407.20		
3	Splenda	25	2	2685.10		
3	Splenda	25	3	2372.60	2488.30	171.31
1	fructose	25	1	1911.50		
1	fructose	25	2	1558.60		
1	fructose	25	3	1428.08	1632.73	250.09
2	fructose	25	1	1890.40		
2	fructose	25	2	1713.10		
2	fructose	25	3	1573.88	1725.79	158.64

Table B.2 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Snap Force (g)	Daily Average Snap Force (g)	Standard Deviation for Daily Mean
3	fructose	25	1	1893.57		
3	fructose	25	2	1614.90		
3	fructose	25	3	1899.70	1802.72	162.69
4	fructose	25	1	1750.50		
4	fructose	25	2	1716.90		
4	fructose	25	3	1728.80	1732.07	17.04
1	fructose	50	1	1768.90		
1	fructose	50	2	1581.70		
1	fructose	50	3	1872.90	1741.17	147.57
2	fructose	50	1	1410.60		
2	fructose	50	2	1583.70		
2	fructose	50	3	1575.20	1523.17	97.58
3	fructose	50	1	1409.10		
3	fructose	50	2	1574.50		
3	fructose	50	3	1658.20	1547.27	126.76
1	fructose	75	1	1554.50		
1	fructose	75	2	1514.95		
1	fructose	75	3	1501.50	1523.65	27.55
2	fructose	75	1	1527.50		
2	fructose	75	2	1516.99		
2	fructose	75	3	1518.56	1521.02	5.67
3	fructose	75	1	1508.10		
3	fructose	75	2	1510.00		
3	fructose	75	3	1514.30	1510.80	3.18
1	fructose	100	1	765.20		
1	fructose	100	2	769.70		
1	fructose	100	3	727.80	754.23	23.00
2	fructose	100	1	691.30		
2	fructose	100	2	705.10		
2	fructose	100	3	619.30	671.90	46.07
3	fructose	100	1	678.30		
3	fructose	100	2	600.40		
3	fructose	100	3	637.70	638.80	38.96
4	fructose	100	1	709.10		
4	fructose	100	2	731.70		
4	fructose	100	3	778.90	739.90	35.62

n = 179

Table B.3 Physical properties of cookies made using sucrose and combinations of sucrose with tagatose, fructose and Splenda.

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Height, H (mm)	Diameter, D (mm)	Spread Ratio (D/H)
1	sucrose	100	1	11.50	74.50	6.48
1	sucrose	100	2	12.00	72.50	6.04
1	sucrose	100	3	11.50	74.50	6.48
2	sucrose	100	1	11.00	75.00	6.82
2	sucrose	100	2	11.00	73.50	6.68
2	sucrose	100	3	12.00	73.50	6.13
3	sucrose	100	1	11.50	74.50	6.48
3	sucrose	100	2	11.50	74.00	6.43
3	sucrose	100	3	11.50	74.00	6.43
1	sucrose	75	1	11.00	71.00	6.45
1	sucrose	75	2	11.00	73.50	6.68
1	sucrose	75	3	11.00	71.00	6.45
2	sucrose	75	1	11.00	71.50	6.50
2	sucrose	75	2	11.00	73.50	6.68
2	sucrose	75	3	11.00	71.50	6.50
3	sucrose	75	1	11.00	72.50	6.59
3	sucrose	75	2	11.00	71.50	6.50
3	sucrose	75	3	11.00	71.50	6.50
1	sucrose	50	1	13.00	63.00	4.85
1	sucrose	50	2	12.50	66.50	5.32
1	sucrose	50	3	13.00	65.00	5.00
2	sucrose	50	1	12.50	65.50	5.24
2	sucrose	50	2	13.00	66.00	5.08
2	sucrose	50	3	13.00	65.00	5.00
3	sucrose	50	1	12.50	66.00	5.28
3	sucrose	50	2	13.00	65.00	5.00
3	sucrose	50	3	13.00	65.00	5.00
1	sucrose	25	1	13.00	56.50	4.35
1	sucrose	25	2	13.00	55.50	4.27
1	sucrose	25	3	13.50	60.00	4.44
2	sucrose	25	1	10.50	60.00	5.71
2	sucrose	25	2	13.00	55.50	4.27
2	sucrose	25	3	13.00	57.50	4.42
3	sucrose	25	1	12.50	60.00	4.80
3	sucrose	25	2	12.00	55.50	4.63
3	sucrose	25	3	13.00	57.00	4.38
1	tagatose	100	1	13.00	67.00	5.15
1	tagatose	100	2	15.00	62.00	4.13
1	tagatose	100	3	12.50	70.50	5.64

Table B.3 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Height, H (mm)	Diameter, D (mm)	Spread Ratio (D/H)
2	tagatose	100	1	15.00	65.00	4.33
2	tagatose	100	2	15.00	65.00	4.33
2	tagatose	100	3	13.00	67.00	5.15
3	tagatose	100	1	12.50	70.50	5.64
3	tagatose	100	2	15.00	65.00	4.33
3	tagatose	100	3	15.00	61.00	4.07
1	tagatose	75	1	15.00	67.50	4.50
1	tagatose	75	2	13.50	67.00	4.96
1	tagatose	75	3	13.00	63.50	4.88
2	tagatose	75	1	13.00	68.50	5.27
2	tagatose	75	2	13.00	69.00	5.31
2	tagatose	75	3	14.00	67.50	4.82
3	tagatose	75	1	13.50	67.00	4.96
3	tagatose	75	2	13.00	65.00	5.00
3	tagatose	75	3	13.50	68.50	5.07
1	tagatose	50	1	12.00	69.00	5.75
1	tagatose	50	2	12.50	70.50	5.64
1	tagatose	50	3	11.50	70.00	6.09
2	tagatose	50	1	13.00	70.50	5.42
2	tagatose	50	1	13.00	70.50	5.42
2	tagatose	50	2	12.00	69.00	5.75
3	tagatose	50	3	12.00	69.00	5.75
3	tagatose	50	1	12.50	70.00	5.60
3	tagatose	50	2	11.50	70.00	6.09
3	tagatose	50	3	12.00	70.50	5.88
1	tagatose	25	1	12.00	71.50	5.96
1	tagatose	25	2	11.90	71.00	5.97
1	tagatose	25	3	11.50	72.50	6.30
2	tagatose	25	1	11.00	71.50	6.50
2	tagatose	25	2	12.00	71.50	5.96
2	tagatose	25	3	12.00	71.50	5.96
3	tagatose	25	1	11.50	71.50	6.22
3	tagatose	25	2	11.50	71.50	6.22
3	tagatose	25	3	12.00	72.50	6.04
1	Splenda	100	1	15.00	54.00	3.60
1	Splenda	100	2	15.00	53.50	3.57
1	Splenda	100	3	14.90	54.50	3.66
2	Splenda	100	1	15.00	55.00	3.67
2	Splenda	100	2	15.00	55.00	3.67
2	Splenda	100	3	15.00	54.00	3.60

Table B.3 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Height, H (mm)	Diameter, D (mm)	Spread Ratio (D/H)
3	Splenda	100	1	15.00	53.50	3.57
3	Splenda	100	2	14.90	54.50	3.66
3	Splenda	100	3	15.00	55.00	3.67
1	Splenda	75	1	13.50	61.00	4.52
1	Splenda	75	2	13.50	60.00	4.44
1	Splenda	75	3	13.25	61.00	4.60
2	Splenda	75	1	14.00	62.00	4.43
2	Splenda	75	2	13.50	61.00	4.52
2	Splenda	75	3	14.00	61.50	4.39
3	Splenda	75	1	13.50	61.50	4.56
3	Splenda	75	2	13.50	60.00	4.44
3	Splenda	75	3	13.25	61.00	4.60
1	Splenda	50	1	12.50	61.50	4.92
1	Splenda	50	2	12.50	62.00	4.96
1	Splenda	50	3	12.00	62.00	5.17
2	Splenda	50	1	13.25	62.50	4.72
2	Splenda	50	2	12.50	61.50	4.92
2	Splenda	50	3	12.50	62.50	5.00
3	Splenda	50	1	13.00	62.00	4.77
3	Splenda	50	2	12.50	62.50	5.00
3	Splenda	50	3	12.50	61.50	4.92
1	Splenda	25	1	11.00	71.50	6.50
1	Splenda	25	2	11.00	71.00	6.45
1	Splenda	25	3	11.50	72.50	6.30
2	Splenda	25	1	11.00	72.00	6.55
2	Splenda	25	2	11.00	72.50	6.59
2	Splenda	25	3	11.25	71.00	6.31
3	Splenda	25	1	11.00	71.00	6.45
3	Splenda	25	2	11.50	72.50	6.30
3	Splenda	25	3	11.00	72.00	6.55
1	fructose	25	1	10.00	68.30	6.83
1	fructose	25	2	10.00	68.00	6.80
1	fructose	25	3	9.50	67.50	7.11
2	fructose	25	1	10.00	67.50	6.75
2	fructose	25	2	9.50	68.00	7.16
2	fructose	25	3	9.70	69.00	7.11
3	fructose	25	1	9.50	69.00	7.26
3	fructose	25	2	10.00	69.00	6.90
3	fructose	25	3	10.00	69.00	6.90

Table B.3 continued …

Day	Sweetener	Percent replacement of sucrose (%)	Replicate	Height, H (mm)	Diameter, D (mm)	Spread Ratio (D/H)
1	fructose	50	1	10.00	72.00	7.20
1	fructose	50	2	10.00	72.00	7.20
1	fructose	50	3	11.50	71.50	6.22
2	fructose	50	1	11.00	70.00	6.36
2	fructose	50	2	8.90	70.50	7.92
2	fructose	50	3	9.00	71.50	7.94
3	fructose	50	1	11.50	71.50	6.22
3	fructose	50	2	11.00	70.00	6.36
3	fructose	50	3	10.50	70.00	6.67
1	fructose	75	1	13.00	69.00	5.31
1	fructose	75	2	11.50	69.00	6.00
1	fructose	75	3	12.50	69.00	5.52
2	fructose	75	1	12.00	70.00	5.83
2	fructose	75	2	12.00	70.00	5.83
2	fructose	75	3	11.00	66.00	6.00
3	fructose	75	1	13.00	69.00	5.31
3	fructose	75	2	12.00	70.00	5.83
3	fructose	75	3	13.00	69.00	5.31
1	fructose	100	1	11.00	70.00	6.36
1	fructose	100	2	10.50	67.00	6.38
1	fructose	100	3	11.00	70.00	6.36
2	fructose	100	1	13.00	71.00	5.46
2	fructose	100	2	12.00	70.50	5.88
2	fructose	100	3	10.50	69.00	6.57
3	fructose	100	1	10.50	67.00	6.38
3	fructose	100	2	11.00	70.00	6.36
3	fructose	100	3	13.00	71.00	5.46

n = 136

Table B.4 Daily average values of physical properties of cookies made using sucrose and combinations of sucrose with tagatose, fructose and Splenda.

Sweetener	Percent replacement of sucrose (%)	Day	Height (mm)	Height std. deviation	Diameter (mm)	Diameter std. deviation	Spread	Spread std. deviation
fructose	25	1	9.83	0.29	67.93	0.40	6.91	0.17
fructose	25	2	9.73	0.25	68.17	0.76	7.01	0.22
fructose	25	3	9.83	0.29	69.00	0.00	7.02	0.21
Splenda	25	1	11.17	0.29	71.67	0.76	6.42	0.10
Splenda	25	2	11.08	0.14	71.83	0.76	6.48	0.15
Splenda	25	3	11.17	0.29	71.83	0.76	6.43	0.12
sucrose	25	1	13.17	0.29	57.33	2.36	4.35	0.09
sucrose	25	2	12.17	1.44	57.67	2.25	4.80	0.79
sucrose	25	3	12.50	0.50	57.50	2.29	4.60	0.21
tagatose	25	1	11.80	0.26	71.67	0.76	6.08	0.20
tagatose	25	2	11.67	0.58	71.50	0.00	6.14	0.31
tagatose	25	3	11.67	0.29	71.83	0.58	6.16	0.10
fructose	50	1	10.50	0.87	71.83	0.29	6.87	0.57
fructose	50	2	9.63	1.18	70.67	0.76	7.41	0.91
fructose	50	3	11.00	0.50	70.50	0.87	6.42	0.23
Splenda	50	1	12.33	0.29	61.83	0.29	5.02	0.13
Splenda	50	2	12.75	0.43	62.17	0.58	4.88	0.15
Splenda	50	3	12.67	0.29	62.00	0.50	4.90	0.12
sucrose	50	1	12.83	0.29	64.83	1.76	5.06	0.24
sucrose	50	2	12.83	0.29	65.50	0.50	5.11	0.12
sucrose	50	3	12.83	0.29	65.33	0.58	5.09	0.16

Table B.4 continued …

Sweetener	Percent replacement of sucrose (%)	Day	Height (mm)	Height std. deviation	Diameter (mm)	Diameter std. deviation	Spread	Spread std. deviation
tagatose	50	1	12.00	0.50	69.83	0.76	5.83	0.23
tagatose	50	2	12.67	0.58	70.00	0.87	5.53	0.19
tagatose	50	3	12.00	0.41	69.88	0.63	5.83	0.21
fructose	75	1	12.33	0.76	69.00	0.00	5.61	0.35
fructose	75	2	11.67	0.58	68.67	2.31	5.89	0.10
fructose	75	3	12.67	0.58	69.33	0.58	5.48	0.30
Splenda	75	1	13.42	0.14	60.67	0.58	4.52	0.08
Splenda	75	2	13.83	0.29	61.50	0.50	4.45	0.06
Splenda	75	3	13.42	0.14	60.83	0.76	4.53	0.08
sucrose	75	1	11.00	0.00	71.83	1.44	6.53	0.13
sucrose	75	2	11.00	0.00	72.17	1.15	6.56	0.10
sucrose	75	3	11.00	0.00	71.83	0.58	6.53	0.05
tagatose	75	1	13.83	1.04	66.00	2.18	4.78	0.25
tagatose	75	2	13.33	0.58	68.33	0.76	5.13	0.27
tagatose	75	3	13.33	0.29	66.83	1.76	5.01	0.06
fructose	100	1	10.83	0.29	69.00	1.73	6.37	0.01
fructose	100	2	11.83	1.26	70.17	1.04	5.97	0.56
fructose	100	3	11.50	1.32	69.33	2.08	6.07	0.53
Splenda	100	1	14.97	0.06	54.00	0.50	3.61	0.05
Splenda	100	2	15.00	0.00	54.67	0.58	3.64	0.04
Splenda	100	3	14.97	0.06	54.33	0.76	3.63	0.06
sucrose	100	1	11.67	0.29	73.83	1.15	6.33	0.25
sucrose	100	2	11.33	0.58	74.00	0.87	6.54	0.37
sucrose	100	3	11.50	0.00	74.17	0.29	6.45	0.03

Table B.4 continued …

Sweetener	Percent replacement of sucrose (%)	Day	Height (mm)	Height std. deviation	Diameter (mm)	Diameter std. deviation	Spread	Spread std. deviation
tagatose	100	1	13.50	1.32	66.50	4.27	4.98	0.77
tagatose	100	2	14.33	1.15	65.67	1.15	4.61	0.47
tagatose	100	3	14.17	1.44	65.50	4.77	4.68	0.84

APPENDIX C

RAW DATA FOR COOKIE DOUGH

Table C.1 TPA measurements of cookie dough made using sucrose alone or in combination with fructose, Splenda and tagatose.

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
1	25	tagatose	1235	1132	1.50	1177	53.66	482	1.49	1702	-260
1	25	tagatose	807	340	1.50	363	27.78	271	1.09	936	-172
1	25	tagatose	1398	1249	1.50	1291	51.21	530	1.36	1866	-281
2	25	tagatose	2421	2004	1.51	2097	108.02	902	1.05	3076	-303
2	25	tagatose	2846	2800	1.51	2908	126.38	1092	1.05	3638	-365
2	25	tagatose	2311	1788	1.51	1879	105.31	858	1.05	2887	-241
3	25	tagatose	1030	1422	1.50	1465	50.25	580	1.45	1360	-527
3	25	tagatose	1149	1470	1.50	1514	51.49	681	1.49	1488	-562
3	25	tagatose	1108	1495	1.50	1538	50.54	628	1.50	1524	-556
4	25	tagatose	676	643	1.50	668	29.71	337	1.49	892	-296
4	25	tagatose	557	328	1.50	343	18.92	238	1.47	662	-251
4	25	tagatose	748	790	1.50	817	31.85	351	1.49	1022	-315
5	25	tagatose	810	866	1.50	899	37.80	486	1.49	1013	-447
5	25	tagatose	897	1023	1.50	1054	37.12	525	1.49	1145	-467
5	25	tagatose	919	912	1.50	947	41.50	481	1.49	1193	-408
1	25	Splenda	2825	2828	1.50	2952	143.96	945	0.99	3871	-339
1	25	Splenda	2323	1987	1.51	2067	95.12	773	1.01	3062	-318
1	25	Splenda	2756	2802	1.50	2916	133.11	900	0.94	3747	-341
2	25	Splenda	1697	1746	1.50	1809	74.68	629	1.17	2327	-295
2	25	Splenda	1892	1954	1.50	2018	77.44	677	1.10	2634	-326
2	25	Splenda	1932	1963	1.50	2027	77.59	691	1.15	2639	-327
3	25	Splenda	1452	1909	1.50	1965	66.12	705	1.43	1936	-462
3	25	Splenda	1676	2334	1.50	2412	89.22	632	0.96	2265	-345
3	25	Splenda	1560	1912	1.50	1977	76.41	679	1.34	2171	-407
4	25	Splenda	711	730	1.50	759	33.43	353	1.49	936	-250
4	25	Splenda	907	791	1.50	822	36.83	400	1.48	1192	-330
4	25	Splenda	969	914	1.50	949	41.11	426	1.49	1282	-317

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
5	25	Splenda	1264	1398	1.50	1452	61.69	713	1.49	1632	-587
5	25	Splenda	1260	1384	1.50	1434	58.10	606	1.47	1627	-389
5	25	Splenda	1386	1485	1.50	1544	68.02	677	1.49	1839	-439
1	25	fructose	860	1074	1.50	1108	39.30	460	1.50	1185	-393
1	25	fructose	855	1046	1.51	1077	36.20	431	1.50	1179	-383
1	25	fructose	1010	1167	1.50	1200	39.54	490	1.50	1363	-445
2	25	fructose	808	1158	1.50	1189	36.32	509	1.50	1074	-532
2	25	fructose	765	1192	1.50	1220	33.51	284	0.78	1085	-299
2	25	fructose	855	1303	1.50	1334	36.99	388	1.07	1242	-402
3	25	fructose	550	1152	1.50	1107	46.09	410	1.63	1194	-483
3	25	fructose	513	1159	1.50	1199	46.37	431	1.62	1213	-432
3	25	fructose	596	1066	1.50	1237	42.63	420	1.67	1074	-532
1	25	sucrose	1688	1606	1.50	1682	87.83	781	1.49	2319	-504
1	25	sucrose	1519	1183	1.50	1239	65.80	693	1.48	1944	-486
1	25	sucrose	1103	656	1.50	691	41.88	455	1.41	1365	-295
2	25	sucrose	2127	2301	1.50	2400	114.41	776	0.96	2974	-284
2	25	sucrose	2101	2182	1.50	2271	103.14	752	0.93	2866	-269
2	25	sucrose	2136	2202	1.50	2286	98.11	736	0.83	2891	-259
3	25	sucrose	2738	3242	1.50	3351	126.06	1422	1.35	3484	-476
3	25	sucrose	2044	2218	1.50	2304	99.05	1022	1.48	2652	-456
3	25	sucrose	2703	3145	1.50	3260	132.41	1492	1.49	3490	-439
1	50	tagatose	1008	866	1.51	896	36.94	400	1.37	1368	-218
1	50	tagatose	1046	1053	1.50	1086	39.77	450	1.49	1431	-260
2	50	tagatose	1068	930	1.50	975	52.10	490	1.45	1351	-276
2	50	tagatose	1132	1172	1.50	1214	49.13	552	1.50	1466	-348
2	50	tagatose	993	913	1.50	945	39.01	444	1.48	1276	-291
3	50	tagatose	879	862	1.50	895	38.87	423	1.48	1132	-287
3	50	tagatose	981	945	1.50	978	38.97	459	1.50	1234	-304
3	50	tagatose	954	935	1.50	965	35.63	422	1.49	1267	-250

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
4	50	tagatose	1531	1336	1.50	1389	62.87	647	1.45	1987	-338
4	50	tagatose	1309	1194	1.51	1243	57.78	573	1.49	1732	-344
4	50	tagatose	1504	1284	1.51	1336	61.92	640	1.49	1994	-406
5	50	tagatose	2045	2030	1.51	2121	105.07	847	1.15	2806	-380
5	50	tagatose	2130	2025	1.51	2106	96.00	840	1.02	2929	-359
5	50	tagatose	1975	1744	1.51	1825	94.03	771	1.08	2682	-330
6	50	tagatose	1037	1408	1.50	1445	43.80	599	1.50	1371	-497
6	50	tagatose	778	935	1.50	960	30.17	401	1.50	1065	-330
6	50	tagatose	878	1041	1.50	1070	34.77	452	1.49	1187	-376
7	50	tagatose	884	1283	1.50	1064	38.48	436	1.50	1293	-492
7	50	tagatose	816	1277	1.50	1018	38.32	422	1.50	1259	-481
7	50	tagatose	880	1275	1.50	1093	38.24	448	1.49	1278	-476
1	50	Splenda	1694	1729	1.50	1793	74.69	642	1.04	2225	-233
1	50	Splenda	1603	1479	1.50	1537	68.59	596	1.13	2122	-254
1	50	Splenda	1694	1729	1.50	1793	74.69	642	1.04	2225	-233
2	50	Splenda	1839	1970	1.50	2036	78.16	631	0.98	2495	-246
2	50	Splenda	1854	1882	1.50	1948	78.47	689	1.05	2471	-299
2	50	Splenda	1772	1617	1.50	1671	66.00	651	1.12	2329	-303
3	50	Splenda	1985	2021	1.50	2101	93.06	616	0.89	2630	-181
3	50	Splenda	2099	2197	1.50	2264	80.97	745	1.04	2799	-295
3	50	Splenda	2034	2136	1.50	2209	86.32	730	1.07	2729	-303
1	50	fructose	584	807	1.50	828	24.56	361	1.19	743	-354
1	50	fructose	474	609	1.50	624	18.83	297	1.50	677	-408
1	50	fructose	516	776	1.50	793	19.71	210	0.86	729	-506
2	50	fructose	414	445	1.50	461	19.11	256	1.49	550	-554
2	50	fructose	675	877	1.50	907	33.90	496	1.49	882	-458
2	50	fructose	531	619	1.50	639	22.90	345	1.49	713	-506

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
2	50	fructose	327	364	1.50	374	11.80	175	1.50	453	-488
3	50	fructose	430	660	1.50	674	19.81	296	1.23	762	-554
3	50	fructose	442	658	1.50	671	19.75	336	1.32	713	-458
3	50	fructose	410	632	1.50	646	18.95	310	1.34	677	-506
1	50	sucrose	842	853	1.50	890	41.92	429	1.48	1063	-294
1	50	sucrose	963	822	1.50	859	42.03	441	1.50	1190	-286
1	50	sucrose	928	681	1.50	710	34.84	393	1.43	1101	-269
2	50	sucrose	1186	1088	1.50	1134	54.08	497	1.47	1553	-293
2	50	sucrose	1579	1485	1.50	1538	63.79	610	1.47	2019	-345
2	50	sucrose	1605	1500	1.50	1552	61.76	654	1.21	2075	-325
3	50	sucrose	1676	1476	1.50	1530	64.51	612	1.17	2196	-284
3	50	sucrose	1319	956	1.50	994	46.04	508	1.28	1609	-284
3	50	sucrose	1664	1556	1.50	1607	61.76	641	1.17	2162	-278
4	50	sucrose	1528	1455	1.50	1515	70.75	591	1.28	2016	-261
4	50	sucrose	1630	1325	1.50	1383	69.33	608	1.29	2112	-289
4	50	sucrose	2104	2087	1.50	2163	89.50	817	1.13	2746	-358
1	75	tagatose	1484	1406	1.50	1468	72.13	647	1.49	2015	-388
1	75	tagatose	1656	1549	1.50	1609	71.04	720	1.49	2219	-458
1	75	tagatose	1507	1346	1.50	1404	67.88	657	1.50	2002	-420
2	75	tagatose	1465	1424	1.50	1483	68.81	642	1.48	1962	-368
2	75	tagatose	1392	1408	1.50	1457	58.87	558	1.18	1902	-286
2	75	tagatose	1504	1514	1.50	1571	67.56	653	1.48	2060	-407
3	75	tagatose	958	1119	1.51	1154	41.30	480	1.49	1773	-392
3	75	tagatose	1113	1340	1.51	1382	49.73	558	1.49	1496	-437
3	75	tagatose	1108	1277	1.50	1321	51.73	564	1.50	1747	-395
4	75	tagatose	1076	1253	1.51	1293	47.19	539	1.49	1411	-466
4	75	tagatose	1258	1502	1.50	1352	48.86	530	1.48	1565	-487
4	75	tagatose	1378	1413	1.51	1401	52.37	600	1.50	1708	-394

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
1	75	Splenda	1691	1629	1.50	1687	69.38	690	1.50	2217	-363
1	75	Splenda	1588	1314	1.50	1365	61.43	591	1.31	2039	-263
1	75	Splenda	1582	1454	1.50	1500	57.25	643	1.37	2084	-330
2	75	Splenda	1685	2011	1.51	2070	69.58	833	1.48	2234	-582
2	75	Splenda	1695	1932	1.51	1994	72.53	752	1.48	2202	-409
2	75	Splenda	1781	2008	1.51	2068	72.09	853	1.49	2318	-540
3	75	Splenda	1329	1501	1.51	1557	65.06	672	1.49	1736	-474
3	75	Splenda	1434	1629	1.50	1688	67.76	701	1.49	1875	-480
3	75	Splenda	1398	1558	1.50	1612	63.55	672	1.49	1787	-458
4	75	Splenda	2682	2634	1.51	2735	119.01	997	1.07	3559	-390
4	75	Splenda	2719	2441	1.51	2541	116.77	1018	1.07	3518	-390
4	75	Splenda	2420	2175	1.51	2268	108.57	884	1.06	3139	-326
4	75	fructose	424	548	1.51	562	16.24	255	1.50	570	-576
5	75	fructose	553	757	1.50	778	24.66	410	1.50	708	-468
5	75	fructose	439	586	1.51	599	16.20	250	1.50	615	-541
5	75	fructose	451	623	1.50	637	17.31	253	1.50	635	-579
6	75	fructose	544	795	1.50	814	22.42	323	1.13	711	-521
6	75	fructose	484	700	1.50	717	19.98	309	1.19	657	-316
7	75	fructose	399	507	1.50	523	18.83	247	1.50	513	-555
7	75	fructose	444	602	1.50	618	18.85	265	1.50	597	-506
7	75	fructose	400	521	1.50	533	14.88	235	1.50	557	-520
1	75	sucrose	1516	915	1.50	969	63.76	479	0.98	1945	-200
1	75	sucrose	1869	1543	1.50	1612	81.78	657	1.17	2479	-281
1	75	sucrose	1691	1629	1.50	1687	69.38	690	1.50	2217	-363
2	75	sucrose	1163	1365	1.51	1408	50.31	549	1.49	1554	-424
2	75	sucrose	1378	1637	1.51	1690	61.88	657	1.50	1832	-491
2	75	sucrose	1467	1737	1.51	1791	64.01	669	1.48	1988	-477

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
3	75	sucrose	1260	1496	1.51	1547	59.40	602	1.46	1649	-424
3	75	sucrose	1367	1584	1.50	1637	61.95	630	1.47	1800	-425
3	75	sucrose	1514	1800	1.50	1863	73.56	692	1.49	2057	-483
3	75	sucrose	1390	811	1.51	856	53.93	472	1.18	1754	-246
4	75	sucrose	3029	2843	1.50	2979	156.98	1003	0.84	4163	-309
4	75	sucrose	2888	2421	1.50	2562	160.63	921	0.77	3880	-253
4	75	sucrose	2693	2327	1.51	2445	135.37	878	0.78	3626	-260
1	100	tagatose	1857	1779	1.50	1854	87.76	761	1.43	2532	-418
1	100	tagatose	2897	2364	1.50	2472	127.76	901	0.94	3945	-338
2	100	tagatose	1907	1532	1.50	1615	95.16	760	1.20	2481	-364
2	100	tagatose	1974	1745	1.50	1834	102.30	856	1.46	2633	-479
2	100	tagatose	1882	1445	1.50	1522	89.04	735	1.22	2483	-365
3	100	tagatose	2475	2128	1.50	2227	116.79	937	1.19	3381	-480
3	100	tagatose	2552	2285	1.50	2392	124.20	962	1.17	3435	-462
3	100	tagatose	2835	2691	1.50	2810	138.41	1108	1.23	3847	-512
4	100	tagatose	2894	3700	1.50	3846	165.31	1018	1.09	4002	-430
4	100	tagatose	3046	3676	1.50	3816	160.21	1253	1.10	4095	-578
4	100	tagatose	3165	3850	1.50	3991	162.01	1499	1.50	4247	-809
5	100	tagatose	1627	1485	1.51	1562	88.08	673	1.14	2128	-308
5	100	tagatose	1081	620	1.51	657	43.92	415	1.31	1278	-256
6	100	tagatose	3181	2868	1.51	3005	158.30	1096	0.96	4262	-350
6	100	tagatose	3184	3357	1.51	3502	167.06	1170	1.00	4384	-373
6	100	tagatose	2387	1625	1.50	1726	115.53	874	0.99	2992	-271
1	100	Splenda	2133	1801	1.50	1877	89.30	1048	1.49	2748	-875
1	100	Splenda	1596	961	1.50	1022	71.07	723	1.47	1941	-684
1	100	Splenda	1949	1563	1.50	1629	78.55	949	1.49	2472	-792

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
2	100	Splenda	2170	1696	1.50	1786	104.06	904	1.32	2856	-531
2	100	Splenda	2487	2124	1.50	2227	118.98	1146	1.47	3245	-812
2	100	Splenda	2164	1780	1.50	1871	105.32	1044	1.49	2792	-854
3	100	Splenda	2422	2224	1.50	2337	128.92	987	1.27	3238	-459
3	100	Splenda	2503	2226	1.50	2335	125.26	1222	1.48	3234	-923
3	100	Splenda	2145	1570	1.50	1654	96.64	1018	1.48	2708	-820
4	100	Splenda	2034	1693	1.50	1913	101.57	956	1.50	2565	-350
4	100	Splenda	2316	1527	1.50	1496	91.59	898	1.50	2742	-312
4	100	Splenda	2522	1491	1.50	1652	89.46	991	1.50	2837	-237
1	100	fructose	399	507	1.51	523	18.83	247	1.50	513	-655
1	100	fructose	400	521	1.51	533	14.88	235	1.50	557	-692
1	100	fructose	444	602	1.50	618	18.85	265	1.50	597	-607
2	100	fructose	442	602	1.50	618	18.36	288	1.50	628	-640
2	100	fructose	427	586	1.50	597	14.55	312	1.50	592	-651
2	100	fructose	439	633	1.50	647	17.41	206	0.96	627	-647
3	100	fructose	449	458	1.50	479	23.46	340	1.49	554	-592
3	100	fructose	456	535	1.50	554	21.91	347	1.49	569	-561
3	100	fructose	379	414	1.50	428	16.27	259	1.49	493	-620
1	100	sucrose	1944	1884	1.50	1968	97.92	670	1.06	2675	-259
1	100	sucrose	1881	1563	1.50	1637	87.00	623	1.02	2516	-251
1	100	sucrose	1872	1608	1.50	1684	88.89	652	1.06	2507	-287
2	100	sucrose	1961	1681	1.50	1773	104.21	857	1.28	2493	-437
2	100	sucrose	2013	1658	1.50	1740	94.94	944	1.48	2546	-656
2	100	sucrose	2011	1560	1.50	1635	88.20	962	1.48	2533	-702
3	100	sucrose	1702	1710	1.50	1773	75.06	659	1.26	2282	-301
3	100	sucrose	1729	1637	1.50	1709	83.62	626	1.22	2328	-276
3	100	sucrose	2074	2030	1.50	2107	90.76	760	1.29	2784	-366

Table C.1 continued …

Day	Percent	Sweetener	Force1	Area4	Length1	Area1	Area5	Area2	Length2	Force2	Area3
4	100	sucrose	2256	2342	1.50	2423	96.13	767	1.05	3055	-326
4	100	sucrose	1945	1915	1.50	1986	84.15	642	1.03	2644	-275
4	100	sucrose	1977	1791	1.50	1858	80.10	685	1.15	2686	-307
5	100	sucrose	2210	2348	1.50	2426	93.00	753	1.07	3057	-327
5	100	sucrose	2537	2530	1.50	2629	115.66	860	1.11	3427	-389
5	100	sucrose	2383	2117	1.50	2196	95.44	834	1.15	3162	-371
6	100	sucrose	1904	1728	1.50	1790	74.72	636	1.06	2557	-271
6	100	sucrose	2061	1898	1.50	1967	82.84	705	1.15	2790	-307
6	100	sucrose	1728	1184	1.50	1246	73.37	565	1.18	2254	-266

Table C.2 Daily average measurements and standard deviations of hardness, adhesiveness and springiness of cookie dough made using sucrose alone or in combination with fructose, Splenda and tagatose.

Day	Percent	Sweetener	Hardness (g)	Hardness std (g)	Adhesiveness (g/s)	Adhesiveness std (g/s)	Springiness	Springiness std
1	25	fructose	1243	105	407	33	1.00	0.00
2	25	fructose	1133	94	411	117	0.74	0.24
3	25	fructose	1160	76	482	50	1.09	0.02
1	50	fructose	716	35	423	77	0.78	0.21
2	50	fructose	649	188	501	40	0.99	0.00
3	50	fructose	717	42	506	48	0.86	0.04
4	75	fructose	570	47	576	40	1.00	0.05
5	75	fructose	653	49	529	56	1.00	0.00
6	75	fructose	684	38	418	145	0.77	0.03
7	75	fructose	556	42	527	25	1.00	0.00
1	100	fructose	556	42	651	43	1.00	0.00
2	100	fructose	616	21	646	5	0.88	0.20
3	100	fructose	539	40	591	29	0.99	0.00
1	25	Splenda	3560	436	332	13	0.65	0.02
2	25	Splenda	2533	179	316	18	0.76	0.03
3	25	Splenda	2124	170	405	58	0.83	0.16
4	25	Splenda	1137	180	299	43	0.99	0.00
5	25	Splenda	1699	121	472	103	0.98	0.01
1	50	Splenda	2191	60	240	12	0.71	0.03
2	50	Splenda	2432	89	283	32	0.70	0.05
3	50	Splenda	2719	85	260	68	0.67	0.06
1	75	Splenda	2113	93	319	51	0.92	0.06
2	75	Splenda	2252	60	510	90	0.98	0.01
3	75	Splenda	1799	71	470	11	0.99	0.00
4	75	Splenda	3405	232	369	37	0.71	0.01

Table C.2 continued …

Day	Percent	Sweetener	Hardness (g)	Hardness std (g)	Adhesiveness (g/s)	Adhesiveness std (g/s)	Springiness	Springiness std
1	100	Splenda	2387	411	784	96	0.98	0.01
2	100	Splenda	2964	245	732	176	0.95	0.06
3	100	Splenda	3060	305	734	244	0.94	0.08
4	100	Splenda	2715	138	300	57	1.00	0.00
1	25	sucrose	1876	481	429	116	0.97	0.03
2	25	sucrose	2910	57	271	13	0.60	0.05
3	25	sucrose	3209	482	457	18	0.96	0.05
1	50	sucrose	1118	65	283	13	0.98	0.02
2	50	sucrose	1882	287	321	26	0.92	0.10
3	50	sucrose	1989	329	282	3	0.80	0.04
4	50	sucrose	2291	397	303	50	0.82	0.06
1	75	sucrose	2212	378	241	58	0.72	0.09
2	75	sucrose	2217	351	363	47	0.99	0.08
3	75	sucrose	1791	220	464	36	0.99	0.01
4	75	sucrose	1815	174	394	103	0.93	0.10
6	75	sucrose	3890	268	274	31	0.53	0.02
1	100	sucrose	2566	95	265	19	0.70	0.02
2	100	sucrose	2524	28	598	141	0.94	0.07
3	100	sucrose	2465	277	314	46	0.84	0.02
4	100	sucrose	2795	226	302	26	0.72	0.04
5	100	sucrose	3215	191	362	32	0.74	0.03
6	100	sucrose	2534	268	281	22	0.75	0.04
1	25	tagatose	1501	496	238	57	0.87	0.13
2	25	tagatose	3200	390	303	62	0.69	0.00
3	25	tagatose	1457	86	548	19	0.98	0.02
4	25	tagatose	859	182	287	33	0.98	0.01
5	25	tagatose	1117	93	441	30	0.99	0.00

Table C.2 continued …

Day	Percent	Sweetener	Hardness (g)	Hardness std (g)	Adhesiveness (g/s)	Adhesiveness std (g/s)	Springiness	Springiness std
1	50	tagatose	1400	44	239	30	0.95	0.06
2	50	tagatose	1365	96	305	38	0.98	0.02
3	50	tagatose	1211	71	280	28	0.99	0.01
4	50	tagatose	1904	149	362	38	0.98	0.01
5	50	tagatose	2806	124	356	25	0.72	0.04
6	50	tagatose	1208	154	401	86	0.99	0.00
7	50	tagatose	1277	17	483	8	0.99	0.00
1	75	tagatose	2079	122	422	35	0.99	0.00
2	75	tagatose	1975	80	354	62	0.92	0.12
3	75	tagatose	1672	153	408	25	0.99	0.01
4	75	tagatose	1561	149	449	49	0.99	0.00
1	100	tagatose	3239	999	378	57	0.79	0.23
2	100	tagatose	2532	87	403	66	0.86	0.10
3	100	tagatose	3554	255	485	25	0.80	0.02
4	100	tagatose	4115	124	606	191	0.82	0.15
5	100	tagatose	1703	601	282	37	0.81	0.08
6	100	tagatose	3880	771	331	54	0.65	0.01

Table C.3 Daily average measurements and standard deviations of cohesiveness, chewiness, resilience of cookie dough made using sucrose alone or in combination with fructose, Splenda and tagatose.

Day	Percent	Sweetener	Cohesiveness	Cohesiveness std	Chewiness	Chewiness std	Resilience (g)	Resilience std (g)
1	25	fructose	0.41	0.01	509	44	0.04	0.00
2	25	fructose	0.32	0.10	487	25	0.03	0.00
3	25	fructose	0.36	0.02	381	45	0.04	0.00
1	50	fructose	0.39	0.11	358	45	0.03	0.00
2	50	fructose	0.53	0.04	350	116	0.04	0.00
3	50	fructose	0.47	0.03	393	24	0.03	0.00
4	75	fructose	0.45	0.04	260	35	0.03	0.00
5	75	fructose	0.45	0.07	295	69	0.03	0.00
6	75	fructose	0.41	0.02	366	12	0.03	0.00
7	75	fructose	0.45	0.02	249	7	0.03	0.00
1	100	fructose	0.45	0.02	269	9	0.03	0.00
2	100	fructose	0.44	0.11	306	10	0.03	0.00
3	100	fructose	0.65	0.06	354	49	0.04	0.01
1	25	Splenda	0.33	0.03	1819	91	0.05	0.00
2	25	Splenda	0.34	0.01	1141	94	0.04	0.00
3	25	Splenda	0.32	0.05	830	96	0.04	0.00
4	25	Splenda	0.47	0.02	539	84	0.05	0.00
5	25	Splenda	0.45	0.04	777	64	0.04	0.00
1	50	Splenda	0.37	0.02	1131	30	0.04	0.00
2	50	Splenda	0.35	0.04	1216	28	0.04	0.00
3	50	Splenda	0.32	0.02	1298	29	0.04	0.00
1	75	Splenda	0.42	0.01	970	51	0.04	0.00
2	75	Splenda	0.40	0.02	909	61	0.04	0.00
3	75	Splenda	0.42	0.01	766	18	0.04	0.00
4	75	Splenda	0.39	0.02	1854	125	0.05	0.00

Table C.3 continued …

Day	Percent	Sweetener	Cohesiveness	Cohesiveness std	Chewiness	Chewiness std	Resilience (g)	Resilience std (g)
1	100	Splenda	0.62	0.08	1471	77	0.06	0.01
2	100	Splenda	0.53	0.03	1646	71	0.06	0.00
3	100	Splenda	0.52	0.10	1679	58	0.06	0.00
4	100	Splenda	0.57	0.06	1548	228	0.06	0.00
1	25	sucrose	0.56	0.10	1051	83	0.06	0.01
2	25	sucrose	0.33	0.00	1576	101	0.05	0.00
3	25	sucrose	0.44	0.02	1487	249	0.04	0.00
1	50	sucrose	0.52	0.04	593	63	0.05	0.00
2	50	sucrose	0.42	0.02	868	200	0.04	0.00
3	50	sucrose	0.44	0.06	1069	89	0.04	0.00
4	50	sucrose	0.40	0.03	1129	234	0.05	0.00
1	75	sucrose	0.45	0.06	1385	126	0.06	0.01
2	75	sucrose	0.41	0.06	913	151	0.04	0.01
3	75	sucrose	0.38	0.01	695	72	0.04	0.00
4	75	sucrose	0.42	0.09	844	264	0.05	0.01
6	75	sucrose	0.35	0.01	2583	117	0.06	0.01
1	100	sucrose	0.37	0.03	1360	61	0.05	0.00
2	100	sucrose	0.54	0.05	1447	64	0.06	0.00
3	100	sucrose	0.37	0.01	1076	81	0.05	0.00
4	100	sucrose	0.34	0.03	1306	67	0.04	0.00
5	100	sucrose	0.34	0.04	1471	120	0.04	0.00
6	100	sucrose	0.39	0.06	1297	6	0.05	0.01
1	25	tagatose	0.52	0.20	840	129	0.06	0.02
2	25	tagatose	0.42	0.04	1925	38	0.05	0.01
3	25	tagatose	0.42	0.03	621	58	0.03	0.00
4	25	tagatose	0.54	0.14	457	12	0.05	0.01
5	25	tagatose	0.52	0.02	581	29	0.04	0.00

Table C.3 continued …

Day	Percent	Sweetener	Cohesiveness	Cohesiveness std	Chewiness	Chewiness std	Resilience (g)	Resilience std (g)
1	50	tagatose	0.43	0.02	638	51	0.04	0.00
2	50	tagatose	0.48	0.02	662	49	0.05	0.01
3	50	tagatose	0.46	0.02	564	19	0.04	0.00
4	50	tagatose	0.47	0.01	910	88	0.05	0.00
5	50	tagatose	0.41	0.01	1590	129	0.05	0.00
6	50	tagatose	0.42	0.00	509	62	0.03	0.00
7	50	tagatose	0.41	0.00	530	4	0.03	0.00
1	75	tagatose	0.45	0.01	947	54	0.05	0.00
2	75	tagatose	0.41	0.03	887	37	0.04	0.00
3	75	tagatose	0.42	0.01	702	78	0.04	0.00
4	75	tagatose	0.41	0.02	651	75	0.04	0.00
1	100	tagatose	0.39	0.03	1697	858	0.05	0.00
2	100	tagatose	0.47	0.01	1405	124	0.06	0.00
3	100	tagatose	0.41	0.01	1809	44	0.05	0.00
4	100	tagatose	0.32	0.06	1634	188	0.04	0.00
5	100	tagatose	0.53	0.14	1070	197	0.07	0.01
6	100	tagatose	0.40	0.09	2316	112	0.06	0.01