THE IMPACT OF DIETARY FIBER AND SUCROSE ALTERNATIVES ON TEXTURE PERCEPTION OF COOKIES

by

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This work is dedicated to my family, friends, and loved ones who have helped me along the way.

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LIST OF ABBREVIATIONS

DSC	Differential Scanning Calorimetry
FOS	Fructooligosaccharides
HFCS	High Fructose Corn Syrup
IMO	Isomalto-oligosaccharides
PCA	Principal Component Analysis
SRs	Sucrose Replacers
T_{gel}	Onset Gelatinization Temperature
a_w	Water activity

ABSTRACT

Low moisture baked goods (cookies, biscuits, etc.) are known for their high sugar content, low water content, and characteristic texture. The added sugar in baked goods has been a concern of health advocates due to the negative health implications of overconsumption of sugar. To minimize these health implications and support healthier food products, the replacement of sugar, sucrose, in low moisture baked goods with alternative sweeteners is of interest. The goal of this study was to improve understanding on how sweetener alternatives and dietary fiber interact with cookie ingredients and the subsequent cookie texture compared to sucrose containing cookies to aid in developing health-conscious low moisture baked goods.

The replacement of sucrose with sucrose replacers (SRs) encompassing a variety of structural and physicochemical properties (high fructose corn syrup (HFCS), amorphous sucrose, maltitol, allulose, isomalt, Benefiber, Miralax, fructooligosaccharides (FOS), and isomalto-oligosacchrides (IMO)) in wire-cut cookies was investigated in terms of starch thermal properties, model cookie formulations, and sensory descriptive analysis. Starch thermal properties were investigated using differential scanning calorimetry (DSC) while wire-cut cookie parameters were analyzed through a_w, color (*a*, *b*, *L*), moisture loss, cookie dimensions (height, width, length), and cookie hardness (N) assays. Sensory descriptive analysis was used to ascertain texture perception of wire-cut cookies through five attributes (hardness, fracturability, pastiness, cohesiveness, and crumbliness).

The onset gelatinization temperature (T_{gel}) was increased to a greater extent than sucrose by Miralax and FOS, and to the same extent by IMO, maltitol, and Benefiber at high concentrations (60%w/w). The SRs which performed similar to sucrose in wire-cut cookie baking (spread, moisture loss, hardness) and texture intensity ratings were amorphous sucrose, maltitol, and allulose. No significant differences in descriptive analysis intensity scores were found in crumbliness, cohesiveness, and pastiness between SRs and sucrose formulated wire-cut cookies. FOS, IMO, and Benefiber displayed significantly larger fracture intensity scores compared so sucrose and isomalt cookies were significantly less hard than sucrose cookies. Principal component analysis (PCA) related SRs effect on starch gelatinization, cookie baking properties, and descriptive analysis intensity scores, and indicated the mostly likely candidates for use in reduced sugar cookies are maltitol and allulose.

CHAPTER 1. LITERATURE REVIEW

The following sections will describe ingredient interactions in a low moisture baked good system, cookies, and methods of analysis. The ingredient interactions section includes a review of the major ingredients present in cookies (sucrose, flour, water, and fat), water-solid interactions, nutritional implications of low moisture baked goods, and strategies for sucrose replacement in cookies. Methods of analysis included a review of how to analyze starch gelatinization, water activity, moisture content, texture properties, and consumer perception of cookies. Due to the glycemic response and subsequent health implications of consuming excess sucrose, replacing sucrose with alternatives has been of interest. However, critical functional properties of sucrose make replacement challenging and these properties are described in the following section.

1.1 Food Chemistry Section

1.1.1 Cookies, a low moisture baked good

Cookies, also referred to as biscuits, fall into a category of low moisture baked goods because of their low moisture content (1-5%) in comparison to bread (35-40%) and cake (15-30%). Cookies are also characterized by the ratios of their major ingredients, sugar, flour, fat, and water. The moisture content of cookie dough is between 11-30%, while the final moisture content of a baked cookie is 1-5%, depending on the cookie type and final product. During baking, the dough changes from an emulsion of lipids in a saturated sucrose solution into a cellular solid as a response to the vaporization of water and gases (Chevallier, Colonna, Buléon, & Della Valle, 2000). In scientific research, there are two AACCI (American Association of Cereal Chemists International) cookie formulations primarily used, wire-cut and sugar snap, which are broadly defined as short dough, characterized by having relatively high sugar and fat content compared to other cookies or biscuits (Table 1). The differences between these two formulations are in the sugar concentration and the total solvent, with sugar-snap cookies having higher values for both (Kweon, Slade, Levine, Martin, & Souza, 2009).

Short dough cookies are typically made through the ‘creaming’ method where all ingredients except for flour are mixed thoroughly to dissolve the sugar while emulsifying the fat

and other ingredients (Manley, 2000). Flour is then added and mixed gently until a reasonably uniform dispersion is reached, but not long enough to promote gluten development. The dough is then pressed or molded in preparation for baking. During baking the dough rises and diameter of the cookie increases, often referred to as 'spread'. Cookie quality is often determined by two main factors, cookie spread and texture. These two qualities are highly influenced by all four major ingredients in cookies: flour, water, sugar, and fat.

Table 1-1 AACCI approved methods for wire-cut and sugar-snap cookie baking.

Ingredients	Standard Weights (g)	
	Wire-cut (AACC 10-53)	**Sugar-Snap (AACC 10-50D)**
Flour	225.0	225.0
Sucrose	94.5	130
Nonfat dry milk	2.3	-
NaCl	2.8	2.1
Sodium bicarbonate	2.3	2.5
Shortening	90.0	64.0
High-fructose corn syrup	3.4	
Ammonium bicarbonate	1.1	
Dextrose solution	-	33.0[a]
Water	49.5[b]	16.0[b]

[a] Dextrose solution was prepared as 8.9 g glucose monohydrate in 150 mL of water
[b] Total water formula is 47.2 g for sugar-snap, 49.5 g for wire-cut based on 225 g flour at 14% water content for sugar-snap and 13% water content for wire-cut.
Table adapted from (Kweon et al., 2009).

1.1.2 Sugar

Sucrose, the most common sugar ingredient used in low moisture baked goods, governs water relationships, gluten development, and starch properties in these products (Pareyt & Delcour, 2008). Sucrose is a non-reducing sugar composed of an α-D-glucopyranosyl unit and a β-D-fructo-furanosyl unit linked by a glycosidic bond. Sucrose is primarily sourced from sugar cane and sugar beets. Through hydrolysis, sucrose can be split into its two molecular constituents, glucose and fructose, in equal portions (Figure 1-1). This hydrolyzed sucrose mixture of glucose and fructose is known as invert sugar, and the process of splitting the sucrose is called inversion (Keppeler &

Arboleda, 1981). The physical state of sucrose, co-formulated ingredients, water content, and temperature can determine the kinetics of sucrose hydrolysis. Invert sugar exhibits different functional properties than sucrose, and therefore imparts different texture and traits in cookies.

High concentration sucrose solutions can be made due to the high solubility and hydrophilicity of sucrose (Damodaran & Parkin, 2017). These highly concentrated sucrose solutions can be used as humectants and preservatives to extend the shelf life of products. In baked goods, sucrose provides the sweet flavor, is hygroscopic, and can crystallize at low water contents. During the dough forming process, sugar aids in creaming air into the fat and maintains moisture. In most short dough, there isn't enough water to dissolve all the sucrose at room temperature. This undissolved sucrose in dough dissolves upon baking causing the cookie to spread. The solubility of sucrose at room temperature (25°C) is 67.0% w/w, and the wire-cut cookie formula contains 66% sucrose concentration (Kweon et al., 2009). Sugars, including sucrose, are plasticizers of the biopolymers of flour but in high concentration aqueous solutions act as antiplasticizers compared to water (Slade, Levine, Ievolella, & Wang, 1993). Aqueous sugar solutions have been shown to be the preferred solvent of flour biopolymers in comparison with water. At high sucrose concentrations, as in wire-cut cookies, doughs are softer than those at low sucrose concentrations (Maache-Rezzoug, Bouvier, Allaf, & Patras, 1998). Doughs with high sucrose concentrations have shown a slowed rate of water uptake by gluten, due to sucrose's effect on solvent quality and quantity (Baltsavias, Jurgens, & van Vliet, 1997).

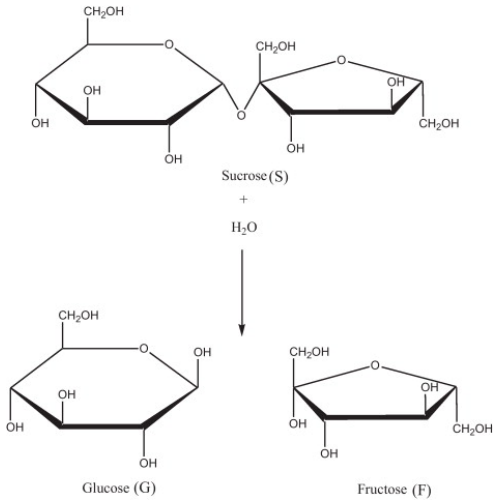

Figure 1-1 Sucrose Hydrolysis

During the baking process, cookies transform from a dough into a cellular solid. As temperature of the dough increases, the undissolved sugar in the dough dissolves causing the cookie to spread (Hoseney, 1994). As baking continues moisture is lost and sucrose solutions become supersaturated. Surface cracking, a common trait in sugar snap cookies, is caused by the recrystallization of sucrose at the cookie surface as the baked cookie cools (Doescher, Hoseney, & Milliken, 1987). Sucrose has been shown to increasingly elevate the gelatinization temperature (T_{gel}) of starch as sugar solution concentration increased (Allan, Rajwa, & Mauer, 2018; Spies & Hoseney, 1982). The mechanism of this T_{gel} increase is not fully known but has been attributed to hydrogen bond density and the ability of sucrose to stabilize the amorphous regions of starch (Allan et al., 2018; van der Sman & Mauer, 2019). The high concentration of sucrose in dough causes an increased T_{gel} of the flour starch in the dough system. As the temperature rises during baking, little starch gelatinizes because of the increased T_{gel}, which aids in the final cookie texture.

After being removed from the oven, wire-cut cookies transition from flexible in texture to hard/crisp as they cool. As the cookie cools, the supersaturated sucrose solutions in the matrix form a glassy sucrose-water matrix. Glassy refers to an amorphous structure lacking three-dimensional order, and cookies with sucrose in this state have reasonably longer shelf life than those in the supercooled liquid (rubbery) state, where sucrose has more molecular mobility and is more likely to crystallize. Storage conditions can also influence the textural and sensory properties of the cookie. If the environmental relative humidity rises above the glass transition temperature (discussed further in water-solids interaction section), the sucrose changes from a glassy state to a rubbery state(Zografi, 1988). In the rubbery state sucrose is more likely to crystallize because of increased molecular mobility, leading to a harder/crisper cookie and diminishing the sensory quality. Environmental temperature also plays a role in the state of sucrose in a cookie system. The term “snap” is often used to describe the hardness or the audible sound the cookie makes when it falls under a load. The unique properties of sucrose and its role as a baking industry standard make reformulation of baked goods with sucrose alternatives difficult.

1.1.3 Flour

Flour consists primarily of starch (70-75%), water (~14%), and protein (8-11%) with values of protein varying between soft and hard wheat (Pareyt & Delcour, 2008). Minor components relevant for baked goods of flour include arabinoxylan, lipids, and non-starch

polysaccharides(Goesaert et al., 2005). In cookie baking soft wheat is primarily used because of its lower protein content, finer granulation, lower water absorption, and less damaged starch in comparison to hard wheat.

Starch, the primary constituent of flour, makes up the majority of digestible carbohydrates in the human diet. Commercial starch products are obtained from a range of natural sources, particularly corn, wheat, rice, roots, tuber, potatoes, and cassava (Damodaran & Parkin, 2017). In nature, starch is present as partially crystalline particles often referred to as granules. Starch granules are composed of two polymers, amylose and amylopectin. Amylose is mostly a linear chain of α-D-glucopyranosyl units linked (1→ 4), but some amylose molecules, 0.3%-0.5% of linkages, contain α-(1→ 6) linkages branched from the main chain (Damodaran & Parkin, 2017). The arrangement of the glycosidic bonds gives the amylose chain a helical shape and most starch granules contain around 25% amylose. Amylopectin molecules are very large and highly branched with 4%-7% of the total linkages being branch points. Amylopectin contains short branches, clustered and occurring as double helices, and long branches, which provide intercluster connections over the length of the molecule. Amylopectin constitutes about 75% of the starch granule.

In the starch granule, there are semicrystalline and amorphous regions. The semicrystalline regions are comprised of dense shells which arise from double-helical branches of amylopectin, stabilized by hydrogen bonds within the chains. The radial arrangement of amylopectin and amylose in the starch granule is observed as birefringence under a polarizing microscope, a pattern which displays as a polarization cross (white background and black cross), with the center indicating the origin of growth for the granule(Whistler, BeMiller, & Paschall, 1984). Depending on the source, starch granules can be different sizes and shapes, giving them slightly different properties when used in cooking.

Starch granules, insoluble in cold water, can lose granular and molecular order when heated in water, through a process called gelatinization (Spies & Hoseney, 1982). During gelatinization, the hydrogen bonds holding the helical structures in the granule together are disrupted causing the helices to unfold and the crystallites to melt. Loss of birefringence, irreversible granule swelling, or loss of crystallinity are all indications that gelatinization or loss of order has occurred. Gelatinization of a population of granules happens over a temperature range and can depend on the starch-to-water ratio, granule type, and on the method of measurement. When measuring

gelatinization, the onset temperature, peak/midpoint temperature, and conclusion temperature are typically all recorded(Damodaran & Parkin, 2017). If heating of the granules continue, after gelatinization, in excess water, the granules will continue to swell. As swelling continues, shear forces can cause amylose to leach from the granule and, leading to total disruption of the granule and paste formation(Whistler et al., 1984). This paste is comprised of solubilized amylose and amylopectin molecules and a discontinuous phase of granule remnants.

Upon cooling and storage of gelatinized starch, there is a reassociation of starch molecules generally called retrogradation. Amylose undergoes retrogradation at more rapid rate than amylopectin, which contain long chains with branches (BeMiller, 2018; Tomasik, 2004). This reassociation can cause precipitation, gelation, or changes in consistency in the starch paste (Karim, Norziah, & Seow, 2000). Eventually, crystallites begin to form which gradually increases the rigidity. These changes can be desirable or undesirable, such as the staling of bread, depending on the food product of interest (see Appendix B). For cookies, retrogradation of gelatinized starch would be undesirable, leading to crumb firmness and loss of freshness. However, in wire-cut cookies little to no starch gelatinizes during baking, leading to limited concern over retrogradation during subsequent storage.

Flour is added as the final ingredient followed by a final mixing step and forming of the dough in wire-cut cookie making. Flour proteins, specifically glutenin and gliadin, can influence rheological properties of cookies. In the presence of sufficient water and mechanical energy, glutenin and gliadin proteins develop into gluten. In wire-cut cookies, there is insufficient water along with interfering substances, high concentrations of sugar and fat, which prevent gluten from developing (Gaines, 1990). This lack of gluten development allows the wire-cut cookies to spread during baking. Flour quality is important for cookie baking due to the different levels of damaged starch present depending on flour source. Soft wheat flours contain minimal damaged starch, undesired due to their high water absorption. A high level of damaged starch can lead to decreased spread in cookies (Hoseney, 1994). During cookie baking, most starch granules fail to gelatinize because of the high sugar content and insufficient water. Chevallier et al. (2000a) found starch granules to be intact in the dough and in the baked cookie center. These ungelatinized starch granules are embedded in the cookie ingredient matrix and help provide support to the cookie structure. Flour, the major component in wire-cut cookies, provides several components important to overall cookie structure and texture.

1.1.4 Fat

The term “fats” refers to a group of food lipids used to mean fats (solid) and oils (liquid). Lipids are chemically diverse but share the trait of solubility in organic solvents. The fatty acid composition of food lipids varies depending on the source, shown in Table 2 (Damodaran & Parkin, 2017). Triacylglycerols, esters of a glycerol molecule and three fatty acid molecules, are naturally abundant in food systems and carry major importance. The three fatty acids in the triglyceride can vary in their number of carbons, degree of unsaturation in the carbon chain, and location on the glycerol backbone, depending on their origin. Lipid molecules can be liquid or solid at room temperature depending on their chain length, degree of unsaturation, polarity, and packing structure (Damodaran & Parkin, 2017). In short dough, “solid fats” are used and consist of fat crystals dispersed in a liquid oil matrix.

In baking, modified natural fat systems, like margarine or shortening, are utilized to deliver more functional characteristics to meet consumer needs. Shortening is used in baked systems to impart tender mouthfeel and rich flavor, despite shortening’s lack of water as a component. During dough formation, fat is mixed with sugar in the creaming stage where air is entrapped and aids in the leavening effect (Lai & Lin, 2006). Shortening functions as a lubricant in the dough, coating flour and sugar particles to reduce mixing time and energy required for mixing. This lubrication effect also helps to reduce gluten development as the fat particles surround the glutenin and gliadin proteins and prevent them from cross-linking (Ghotra, Dyal, & Narine, 2002). The solid fat index (SFI), ratio of solid fat to total fat, of the shortening can determine the functional performance and quality. The crystal structure of the solid fat along with the SFI can determine the plasticity of the shortening. Amylose and lipids form a complex during baking delaying the transport of water into the starch granule which delays starch gelatinization (Larsson, 1980). When cookies are placed in the oven, shortening melts, making it more free to flow under gravitational force and aids in cookie spread.

Table 1-2 Fatty acid composition of common foods.

TABLE 4.2
Fatty Acid Composition (%) of Common Foods

Food	4:0	6:0	8:0	10:0	12:0	14:0	16:0	16:1 Δ9	18:0	18:1 Δ9	18:2 Δ9	18:3 Δ9	20:5 Δ5	22:6 Δ4	Total Sat'd
Olive							13.7	1.2	2.5	71.1	10.0	0.6			16.2
Canola							3.9	0.2	1.9	64.1	18.7	9.2			5.5
Corn							12.2	0.1	2.2	27.5	57.0	0.9			14.4
Soybean						0.1	11.0	0.1	4.0	23.4	53.2	7.8			15.0
Linseed							4.8		4.7	19.9	15.9	52.7			9.5
Coconut		0.5	8.0	6.4	48.5	17.6	8.4		2.5	6.5	1.5				91.9
Cocoa						0.1	25.8	0.3	34.5	35.3	2.9				60.4
Butterfat	3.8	2.3	1.1	2.0	3.1	11.7	26.2	1.9	12.5	28.2	2.9	0.5			62.7
Beef fat				0.1	0.1	3.3	25.5	3.4	21.6	38.7	2.2	0.6			50.6
Pork fat				0.1	0.1	1.5	24.8	3.1	12.3	45.1	9.9	0.1			38.8
Chicken					0.2	1.3	23.2	6.5	6.4	41.6	18.9	1.3			31.1
Atlantic Salmon						5.0	15.9	6.3	2.5	21.4	1.1	0.6	1.9	11.9	23.4

Only the major fatty acids in these products are listed. All fatty acid compositions are adapted from White [93] with the exception of Atlantic Salmon, which is adapted from Ackman [1].

1.1.5 Water

Water, two hydrogen atoms covalently linked to an oxygen atom, is an important component of food systems. Water contains many unique properties, several of which are relevant to cookies at all stages of production. Water acts as a plasticizer and, as it interacts with food ingredients, changes in physical and chemical properties are likely to occur, affecting product quality. To understand the importance of water interactions in cookies, we must first examine water-solid interactions and the concept of water activity.

Water Activity

Understanding water activity, a_W, is important in respect to enhancing food shelf-life, limiting microbial growth, reducing powder caking, and fundamentally knowing the driving force behind water movement within foods and between foods and the environment. Water activity is thermodynamically defined as fugacity of a solution (f) in relation to the fugacity of pure solvent (f_o) at equilibrium. Fugacity is defined as tendency of a solvent to escape from solution (Lewis, Randall, Pitzer, & Brewer, 1961). At low pressure there is less than a 1% difference in fugacity above the sample over the fugacity of pure water (f/f_o) and vapor pressure above the sample divided by the vapor pressure of pure water (p/p_o), therefore, a_W can be defined as (Zografi, 1988):

$$a_W = p/p_o \qquad \text{Equation 1-1}$$

Another way to express a_w is by relative vapor pressure (RVP) which is the percent equilibrium relative humidity (%ERH).

$$a_W = RVP = \%ERH/100 \qquad \text{Equation 1-2}$$

Determining a_W in solid or semisolid foods can be difficult due to the assumptions that (1) thermodynamic equilibrium between the water in the food and the vapor phase over the food has to be established in a closed system, and (2) the nonaqueous food components can't undergo phase change after storage (Damodaran & Parkin, 2017). True equilibrium may take several days or longer to achieve in solids and semisolid systems, and solutes may undergo phase changes from amorphous to crystalline over time.

Water-solid interactions

It is important to note that water does not covalently bond to food ingredients, but interacts via hydrogen bonds, dipole-dipole interactions, ionic interactions, and van der Waals forces (Damodaran & Parkin, 2017). When discussing water-solid interactions, the state of the solid, crystalline or amorphous, is highly important. Crystalline solids have long-range three dimensional order and are more thermodynamically stable than amorphous materials. Amorphous solids do not have long-range three dimensional order, exhibiting instead random and disordered molecular arrangement(Bhandari & Roos, 2017). At a characteristic temperature, the glass transition temperature (T_g), amorphous solids transition from a 'glassy state' below the T_g to a 'rubbery' or 'supercooled liquid' state above the T_g. There is limited mobility in the 'glassy' state, where as in the 'rubbery' state there is greater translational freedom. Water interactions with solids include surface interactions (adsorption), condensed water (capillary condensation and deliquescence), and internalized water (absorption and crystal hydrate formation) shown in Figure 1-2 (L. J. Mauer & Bradley, 2017). Amorphous solids interact most significantly with water via absorption but can also experience adsorption and capillary condensation (Zografi, 1988). Crystalline solids sorb moisture through adsorption, capillary condensations, deliquescence, and/or crystal hydrate formation. Adsorption occurs at the hydrophilic surface of a polar solid where water molecules affix themselves via hydrogen bonding. Smaller molecules adsorb more water due to the increase surface area to mass ratio, relative to larger molecule. Despite temperature and pressure effects on

water adsorption, the amount of water adsorbed at the surface is small and not significant in reference to dissolution of the solid (L. Mauer, 2015). Deliquescence is defined as the first-order phase transformation of a crystalline solid to a saturated solution. This occurs when the environmental relative humidity exceeds the deliquescent point (RH_0), the critical RH characteristic of the crystal(L. J. Mauer & Taylor, 2010). Sugars are an important deliquescent ingredient in baked goods. Capillary condensation occurs as RH approaches RH_0 and water vapor condenses in a solid pore or at a contact point between two particles. Crystal hydrates are formed when the level of moisture present is high and a significant change thermodynamic properties occur in the molecules involved(Zografi, 1988). Absorption, occurring only in amorphous ingredients, uptakes water vapor into the bulk of the amorphous solid. This happens to a greater degree than that of adsorption and can affect the glass transition temperature (T_g), causing the transition of amorphous solids from the glassy to the supercooled liquid state as the T_g is lowered below environmental temperature. The increased molecular mobility of the supercooled liquid state can lead to crystallization of the solids, especially as RH is increased. These water-solid interactions have implications for the physical and chemical stability of food systems, including low-moisture baked goods.

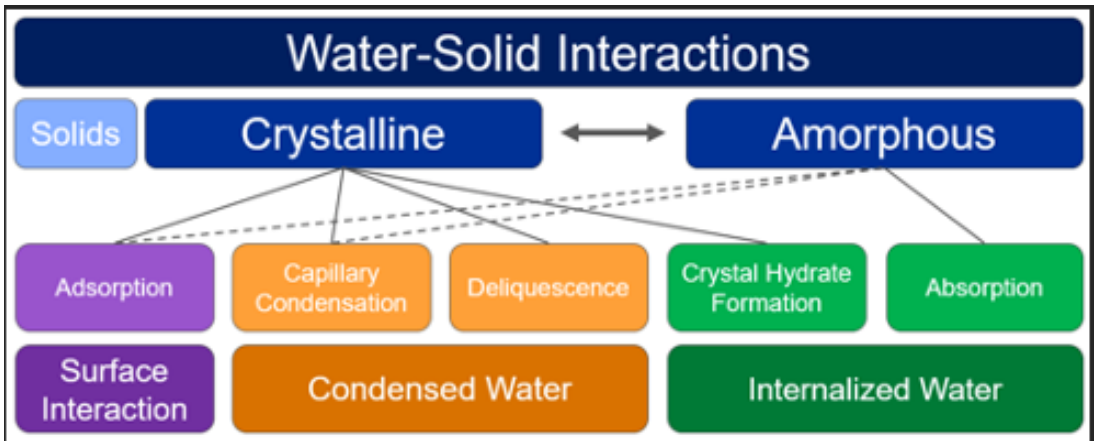

Figure 1-2 Overview of the major mechanism for water-solid interactions adapted from Mauer and Allan (2015).

Water in dough systems

In dough, water is necessary for the solubilization of other ingredients and aids in the dispersion of dry ingredients with fat. Depending on the type of dough, the level of water greatly

affects the outcome of the product. In short dough, a low amount of water is needed to achieve the texture properties desired. The water content of short doughs can range from 11% to 30% depending on the formulation (Table 1). The low moisture content of dough and the limited mixing prevents gluten development, an undesirable trait in wire-cut cookies. Cookie spread, an important predictor of quality, is controlled by the viscosity of the dough. The dough viscosity is governed by competition between ingredients for available water (Hoseney, 1994). Increasing the formula water content has been shown to increase the spread rate, but not the final diameter, likely due to an increase in gluten development (Hoseney, 1994).

A moisture gradient exists in baked wire-cut and sugar-snap cookies with the highest moisture content in the center of the product and the lowest moisture content on the surface. During cooling and storage this gradient disappears due to moisture migration, leading to possible changes in texture and quality. If there is a large moisture gradient from the center of the cookie to the surface 'checking', hairline crack formation, can occur leading to spontaneous breakage (Cornillon & Salim, 2000). In sugar-snap and wire-cut cookies, it is the limited amount of water that gives the desire structure and quality. Storage conditions, especially temperature and relative humidity, can affect the textural properties of cookies. Moisture loss or gain can cause textural changes, microbial growth, or chemical spoilage. For example, if the environmental temperature rises past the T_g, the sucrose present in the glassy state transitions to the supercooled liquid state where it is more likely to crystallize. If crystallization does occur, sucrose crystallizes as an anhydrous structure and the water redistributes to interact with the other cookie components. This crystallization causes the cookie to become harder and is generally considered 'staling'.

1.1.6 Low-moisture baked goods

Wire-cut and sugar-snap cookies fall into a general category known as low-moisture baked goods. Other baked goods in this category includes crackers, cookies, and pretzels. Barden and Decker describe low moisture baked goods having a water activity of less than 0.5 (Barden & Decker, 2016). Sucrose is utilized in low-moisture baked goods at different concentrations. Crackers usually contain less than 30% sucrose concentration while cookies contain a sucrose concentration of greater than 30% (Kweon, Slade, Levine, & Gannon, 2014). As discussed above, sucrose plays an important role in low-moisture baked goods, governing starch properties, gluten development, and water relations. However, consumption of sucrose in baked goods, including

low-moisture baked goods, can be bad for human health. Sweet bakery products are the second main source of added sugars in individuals over two years old (Bailey, Fulgoni, Cowan, & Gaine, 2018). The nutritional effects of the sugars in low-moisture baked goods is discussed further in the following section.

1.1.7 Nutritional implications of added sugars

Due to the potential health implications of consuming excess sucrose, replacing sucrose with alternatives has been of interest. Sucrose replacement comes with challenges due to it's unique properties. The effects of dietary sugar on health have been extensively studied in recent times. Excessive added sugar intake has been correlated to lower diet quality, obesity, cardiovascular disease, type 2 diabetes, and some cancers (Bes-Rastrollo, Sayon-Orea, Ruiz-Canela, & Martinez-Gonzalez, 2016; Imamura et al., 2015; Louie & Tapsell, 2015). The Dietary Guidelines for Americans 2020-2025, provided by the USDA (United States Department of Agriculture), provides a guideline recommending to limit foods and beverages high in added sugars. More specifically, these guidelines suggest including less than 10 percent of calories per day from added sugars (*Dietary Guidelines for Americans, 2020-2025*, December 2020). Excluding elders and infants, average consumption of added sugar is greater than 10% of total energy across many countries worldwide (Newens & Walton, 2016). 'Added sugar' includes only the monosaccharides and disaccharides purposely added to a product, but excludes sugars naturally present in fruits and fruit juices (Bailey et al., 2018). Baked goods are a primary source of added sugars in the American diet and according to a 2021 Mintel report, 77% of cookie consumers eat cookies on a weekly basis (Kamp, 2021; Martínez Steele et al., 2016). Due to the health implications of added sugars, consumers are interested in reducing their sugar intake. Most consumers who are lowering their cookie intake are doing so to try and lose weight and reduce their sugar intake (Kamp, 2021). Reducing the amount of added sugar in low-moisture baked goods, and replacing sugars with dietary fiber, could create products attractive to consumers; however, the technical challenges of replacing the functionality of the added sugars are numerous.

1.1.8 Sucrose reduction and replacement strategies

Two main strategies of reducing sucrose consumption from cookies are (1) reduce the amount of sucrose, or (2) replace the sucrose. These strategies have been studied by many with a variety of methods and outcomes.

The first strategy, reducing the amount of sucrose, shows a reduction in sensory ratings for sweetness and likeness as the sucrose content declined (Biguzzi, Schlich, & Lange, 2014; Drewnowski, Nordensten, & Dwyer, 1998). Two studies reduced sucrose by 25-100% in cookies and found reformulation was not feasible at any of these contents due consumers considering the quality to be unacceptable (Drewnowski et al., 1998; Martínez-Cervera, de la Hera, Sanz, Gómez, & Salvador, 2012). Overall, these studies have shown sugar reduction further than 10% will result in textural and sensory defects in cookies.(Luo, Arcot, Gill, Louie, & Rangan, 2019).

The second strategy, replacing the sucrose, has been explored to a greater extent than the reduction of sucrose. These strategies include partial replacements as well as full replacements. Sugar alcohols are carbohydrates lower in calories and produce a lower glycemic index response than sucrose because they are not fully digested by humans. Sugar alcohols are used in products for individuals with diabetes and are a popular replacement because of their sweetness. However, most sugar alcohols are less sweet than sucrose and have a laxative effect when consumed in excess. Cookie formulations with xylitol lead to a harder dough, but xylitol co-formulated with a non-nutritive sweetener most resembled the sucrose control (Kutyła-Kupidura et al., 2016). Non-nutritive sweeteners are molecules that provide a higher intensity of sweetness compared to sucrose. Sorbitol has been investigated in cookies and lead to a softer product than sucrose, but sorbitol has potential as a partial replacer (EI Zoulias, Oreopoulou, & Kounalaki, 2002). Maltitol and isomalt have been shown to be suitable sucrose replacers in muffins, but haven't been fully investigated in cookies (Martínez-Cervera, Salvador, & Sanz, 2014). The physicochemical differences in cookies made with sugar alcohols versus sucrose can be attributed to the molecular weight, solubility, and hygroscopicity differences between sweeteners (Luo et al., 2019).

Commercially available sweeteners, which often include non-nutritive sweeteners, have also been investigated. Non-nutritive sweeteners (NNS) have high potency of sweetness and small quantities are required to match the sweetness of sucrose in baked goods; however, they do not provide the bulk needed to match the texture of sucrose containing products. To solve this problem, NNS are paired with bulking agents, such as maltodextrins or inulin, in commercially available

sweeteners. Inulin, which has also been investigated as a fat replacer, has potential for partial sucrose replacement, but only shows sensory acceptability at low levels of substitution (Antonios, Elpida, & Ioanna, 2021). Some studies have found NNS to be suitable replacements in baked goods, including cookies, if formulated along with bulking agents (Aggarwal, Sabikhi, & Sathish Kumar, 2016; Emmanuel I. Zoulias, Piknis, & Oreopoulou, 2000). Consumer concern over the synthetic origin of some NNS has turned interest toward more naturally sourced options, like oligosaccharides and dietary fiber.

Oligosaccharides, containing 2-20 sugar units joined by glycosidic bonds, and polysaccharides, larger polymers of monosaccharides, can be added as a bulking agent in cookies to lower the added sugar profile. Some oligosaccharides are prebiotics, sometimes called dietary fiber, and are not digested by human digestive enzymes (Mitchell, 2006). Inulin and fructo-oligosaccharides are fructose polymers and have been investigated in cookies as partial sucrose replacements with some success. In one study, inulin replaced 25% of sucrose without negatively impacting texture and sensory analysis (Laguna, Primo-Martín, Salvador, & Sanz, 2013). A study on twelve commercially available sweetener products showed oligosaccharide containing ingredients showed promise in replacing sucrose in wire-cut cookies, but the study did not investigate sensory aspects of these cookies (Woodbury, Lust, & Mauer, 2021). Further investigation is needed to determine if dietary fiber can be used to lower added sugar in cookies and other low-moisture baked goods while maintaining sensory quality.

1.2 Methods of Analysis

To determine if sucrose can be replaced in cookies, a range of methods are used to determine different physicochemical characteristics of the replacers in comparison to sucrose. Analysis may include solution properties, starch interactions, baking parameters, sensory testing, and textural analysis.

1.2.1 Gelatinization Temperature

To measure gelatinization of starch, differential scanning calorimetry (DSC) is used because of it's ability to measure endothermic processes. Water acts as a plasticizer and when the starch amorphous region is in the presence of at least 60% water and a specific temperature, known as

the glass transition temperature, is reached a phase transition occurs from the glassy state to the rubbery state. This glassy to rubbery transition may occur below room temperature, so the T_g of starch is not often measured. Gelatinization, the melting of the crystalline regions in starch, is commonly measured with the onset and peak gelatinization temperatures and the enthalpy of crystallite melting often reported. DSC endotherms are used to identify matches between ingredient functionality and baking performance to aid in the development or reformulation of products (Slade, Levine, Wang, & Ievolella, 1998). Figure 1-3 shows the gelatinization pattern obtained from DSC analysis of starch and water mixtures. In the presence of increasing sugar concentration, the endotherm and T_{gel} shift to a higher temperature (Figure 1-3). Sugar-starch relations in cookies largely determine the texture and quality, making the effects of formulation on starch T_{gel} important to study if sucrose replacement is to be achieved. To aid in determining the best sucrose replacement in cookies a DSC method can be utilized to explore how different sucrose replacers interact with starch and which closely resembles sucrose.

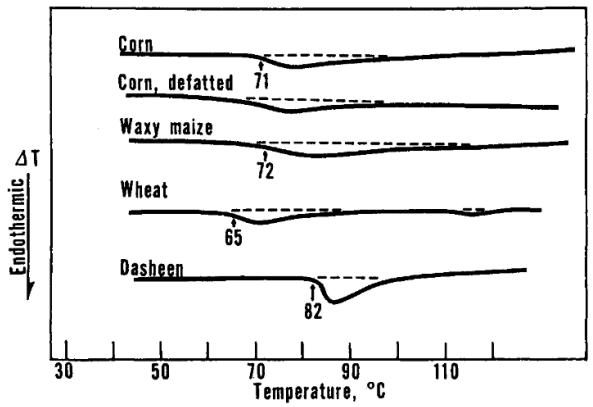

FIG. 1.—Gelatinization endotherms of granular starches with A-type X-ray structures.

Figure 1-3 Gelatinization patters for several types of cereal starch using a 1:1 water-starch ratio (Whistler et al., 1984).

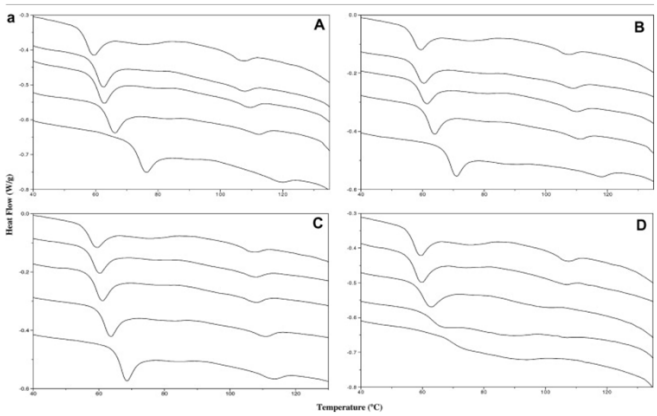

Figure 1-4 DSC curves in the presence of 0%, 5%, 10%, 20%, and 40% sucrose (A), glucose (B), glycerol (C), and HPß-CD (D) with increasing concentration from top to bottom (Gunaratne, Ranaweera, & Corke, 2007).

1.2.2 Moisture content and water activity

As previously described, the water content of dough and the resulting cookie are important to the quality and texture characteristics of cookies. AACCI methods are typically utilized to determine the moisture contents of doughs. The AACCI method 44-01.01 is based on a simple % moisture loss calculation and is commonly used when discussing moisture contents of doughs. Moisture content of the baked cookie is measured by the difference in weight of the cookies before and after baking and is reported as % moisture lost (Kweon et al., 2009).

Water activity has been related to texture, specifically crispiness, in low-moisture baked goods (Katz & Labuza, 1981). There are two main ways to measure water activity, chilled mirror dew point or electric hygrometer. Decagon Devices Aqualab (METER Group, Inc, Pullman, WA) is a dew point analyzer utilized for water activity measurements in cookies (Gerzhova, Mondor, Benali, & Aider, 2016; Patrignani, Conforti, & Lupano, 2014). Dew point analyzers work by equilibrating a sample in a temperature-controlled chamber containing a fan to circulate headspace(L. J. Mauer & Bradley, 2017). Sample temperature is measured with an infrared thermometer and a sensor detects condensation on the mirror. When using a water activity meter, it is important to know potential volatile compounds in the samples as certain volatile compounds may condense on the mirror of the dew point analyzer and alter results (L. J. Mauer & Bradley, 2017).

1.2.3 Texture Analysis

An important quality parameter of cookies is their texture. Texture analyzers are used to measure hardness, crispness, and cutting strength of cookies through a number of different probes. The 3-point bending test uses the 3-point bending rig to measure the fracture force (maximum) as hardness at the point when the cookies are broken into two major pieces (Mudgil, Barak, & Khatkar, 2017). This peak force represents the breaking strength of the cookie. Penetration test are also used on low-moisture baked goods with the maximum force described as the point at which the probe hit its maximum penetration depth (Brighenti, Govindasamy-Lucey, Lim, Nelson, & Lucey, 2008). The texture analyzer can be set up with different distances to penetration and test speeds. Despite being able to investigate product hardness with the texture analyzer, the way a consumer interacts with a product, and perceives its texture, can be very different.

1.2.4 Sensory Analysis

Sensory analysis is a tool established to determine the worth of a commodity or its acceptability to the consumer. The instrument of sensory analysis, human subjects, can vary over population, and time, and are very prone to bias. The type of sensory test utilized for a study is dependent on the sensory attributes of interest and the product being studied. A key factor in reformulating products is maintaining consumer acceptance and liking of the new formulation, especially when compared to a "gold standard" starting product. In sugar-reduced cookies, sensory changes in the reduced sugar products have included changes in: sweetness, hedonic, acceptability, crispiness, hardness, and color. When reformulating cookies with sucrose replacers, matching texture seems to remain the biggest obstacle. Previous work evaluating cookie texture has utilized descriptive analysis panels to explore texture perception in cookies and other low-moisture baked goods (Biguzzi et al., 2014; Mello, Almeida, & Melo, 2019; EI Zoulias et al., 2002).

Descriptive analysis is a method of sensory evaluation utilized when discrimination and detection of both qualitative and quantitative traits of a product are required (Lawless, 2010). A panel of trained judges work to distinguish products through specific qualities including; aroma, appearance, flavor, and texture (Murray, Delahunty, & Baxter, 2001). Methods for descriptive analysis vary with some of the most common being the Texture Profile Method (Brandt, Skinner, & Coleman, 1963), Quantitative Descriptive Analysis™ (Stone, Sidel, Oliver, Woolsey, &

Singleton, 2008), Flavor Profile Method (Cairncross & Sjostrom, 2004), and the Spectrum™ Method (Meilgaard, 2016). To achieve a specific objective, different approaches are combined to develop a more generic descriptive analysis to allow for a more practical application. This method of analysis is often utilized in quality control settings but can also be used to track changes during shelf-life testing, investigate effects of ingredient changes, or for sensory mapping. In formulating cookies with different sucrose replacers, descriptive analysis is primarily used to investigate effects of ingredient changes or reformulations.

When designing a sensory study, there are certain human behaviors important to keep in mind as they may affect the outcome of the study. Dumping is a phenomena in sensory science occurring when a negative attribute of a sample is left off of the questionnaire (Lawless, 2010). If the consumer finds a quality of the sample dissatisfactory but rating for the quality isn't an option, they will dump this frustration into a negative rating for a different, unrelated quality. This effect is a common when studying sweetness enhancement. Sweetness ratings have shown enhancement with fruity odors when the fruity odor was not rated (Frank, Klaauw, & Schifferstein, 1993). This effect demonstrates the importance of selecting attributes for rating during consumer testing. The halo effect typically refers to a positive correlation between two unrelated subjects. The opposite of this, the horns effect, refers to a negative correlation between two unrelated attributes. This effect is minimized with the use of trained panels but needs to be accounted for when examining consumer panels. A halo effect could lead to a bias in the obtained results if not taken into account when designing the study. In cookies, the lack of sweetness in a product could lead to a negative correlation with another attribute if panelists are not asked to rate sweetness.

1.3 Summary

The main objectives addressed in this research was to investigate the effects of sucrose and sucrose replacers on the texture of wire-cut cookies and consumer perception of the potential textural changes. Due to the nutritional implications of sucrose on human health it is important to investigate alternatives for sucrose in low-moisture baked goods. Sucrose interactions with cookie ingredients are numerous and important to the final structure of wire-cut cookies which makes replacement strategies difficult. Different sucrose replacers have been investigated but an ideal replacer has not been achieved.

To better understand the effect of sucrose replacers on the texture of wire-cut cookies, a study was developed. The second chapter investigates the effect of different dietary fibers and sucrose replacers on the perceived texture of wire-cut cookies. This study explored the effects sucrose replacers on starch thermal properties (T_{gel}), wire-cut cookie baking performance, and perceived texture via a descriptive analysis panels.

1.4 References

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CHAPTER 2. THE IMPACT OF DIETARY FIBER AND SUCROSE ALTERNATIVES ON TEXTURE PERCEPTION OF COOKIES

2.1 Abstract

The objective of this study is to link starch thermal properties (T_{gel}) and wire-cut cookie parameters to perceived texture through sensory descriptive analysis. Differential scanning calorimetry was used to investigate starch thermal properties while wire-cut cookie parameters were analyzed through a_w, color (*a, b, L*), moisture loss, cookie dimensions (height, width, length), and cookie hardness (N) assays. Sensory descriptive analysis was used to ascertain texture perception of wire-cut cookies through five attributes (hardness, fracturability, pastiness, cohesiveness, and crumbliness). The 10 sucrose replacers used in this study were: high fructose corn syrup (HFCS), amorphous sucrose, maltitol, allulose, isomalt, Benefiber, Miralax, fructooligosaccharides (FOS), and isomalto-oligosacchrides (IMO). Principal component analysis (PCA) related sucrose replacers effect on starch gelatinization, cookie baking properties, and descriptive analysis intensity scores. The onset gelatinization temperature (T_{gel}) was increased to the same extent as sucrose by IMO, maltitol, and Benefiber and to a greater extent than sucrose by Miralax and FOS at 60% w/w solution concentration. The sucrose replacers which performed most similarly to sucrose in wire-cut cookie baking (spread, moisture loss, hardness) were amorphous sucrose, maltitol, and allulose. FOS cookies were significantly darker than sucrose cookies. Cohesiveness and pastiness intensity values had a significant overall effect, but there were no significant differences between cookies formulated with sucrose and sucrose replacers. FOS, IMO, and Benefiber displayed significantly larger fracture intensity scores compared to sucrose. Isomalt cookies were significantly less hard than sucrose cookies. Overall, allulose and maltitol are the most likely candidates for sucrose replacement in reduced sugar cookies based on the properties measured and related through principal component analysis.

2.2 Introduction

Baked goods, a primary source of added sugars in the American diet, are a popular snack. According to a Mintel report, 77% of cookie consumers eat cookies on a weekly basis (Kamp, 2021; Martínez Steele et al., 2016). The Dietary Guidelines for Americans 2020-2025 suggests

including less than 10 percent of calories per day from added sugars in a standard diet, but studies show average consumption of added sugar among adults is much higher than this recommendation (*Dietary Guidelines for Americans, 2020-2025*, December 2020; Newens et al., 2016). Excess added sugar in the diet can contribute to lower diet quality, obesity, cardiovascular disease, type 2 diabetes, and some cancers (Bes-Rastrollo et al., 2016; Imamura et al., 2015; Louie et al., 2015). Consumer interest in healthier food alternatives has led the food industry to explore alternative sweeteners (dietary fiber, sugar alcohols, and natural sucrose replacers) in a variety of products.

Developing reduced-sugar products containing alternative sweeteners poses many difficulties due to sucrose, the main sugar added to bakery products, being the gold-standard in the baking industry. In low-moisture baked goods, like cookies, sucrose is especially difficult to replace as it governs flavor and texture through control of water relations, gluten development, and starch properties (Hoseney, 1994; Pareyt et al., 2008). In cookies, the important physicochemical properties of sucrose include it's high solubility, hygroscopicity, crystallinity, melting temperature (186 °C), and nonreducing characteristic (Pareyt et al., 2008). The main indicators of cookie quality are texture, spread, and surface cracking (Pareyt et al., 2008). The role of sucrose in limiting starch gelatinization (by elevating the gelatinization temperature, T_{gel}), delaying gluten development, and recrystallization at the cookie surface all play a role in cookie quality (BeMiller, 2019; Doescher et al., 1987; Hoseney, 1994).

Numerous studies have investigated the effects of sucrose replacement with a variety of other ingredients on cookie baking parameters and final texture (Biguzzi et al., 2014; Kweon et al., 2016; Laguna et al., 2013; Pareyt et al., 2009; Taylor et al., 2008; Woodbury et al., 2021). In addition to physicochemical analyses of the cookies, sensory analysis has been utilized to understand the consumer perception of reformulated cookies (Laguna et al., 2012; Mello et al., 2019; Zoulias et al., 2002). Descriptive analysis, a sensory methodology, is used to distinguish products through specific qualities, including texture, and has been used to evaluate cookies (Lawless, 2010). To expand on the current knowledge of sucrose replacement in cookies, texture descriptive analysis for a variety of sucrose replacers needs further investigation, and this could be especially useful in a study that does both sensory analysis and physiochemical analysis of the same cookie formulations.

Reformulated reduced-sugar cookies could be attractive to health-conscious consumers; however, there is a need to better understand the landscape of effects of sucrose-replacing

ingredients on cookie traits and sensory perception in order to develop acceptable, desirable products. The objective of this study was to investigate the effects of a variety of sucrose replacers with different physicochemical traits on wheat starch thermal properties (T_{gel}), model cookie baking performance, and sensory perception of cookies through descriptive analysis.

2.3 Materials and Methods

2.3.1 Materials

Sucrose and sucrose replacers (SRs) used in this study were sourced commercially and included: Benefiber® (GSK Consumer Healthcare, Warren, NJ, USA), Miralax® (Bayer Healthcare LLC, Whippany, NJ, USA), allulose (Tate & Lyle PLC, London, UK), Isomalt (Beneo GmbH, Mannheim, Germany), sucrose (Great Value, Bentonville, AR, USA), isomaltooligosaccharide (Vitafiber®), maltitol (Alfa-Aesar, Haverhill, MA, USA), fructooligosaccharide (FOS) DP 3-5 (Beneo GmbH, Mannheim, Germany), high fructose corn syrup (HFCS) (Tate and Lyle PLC, London, UK) (Table 2-1). Amorphous sucrose was made from sucrose using a Nostalgia^{TM} cotton candy maker (Green Bay, WI, USA) and analyzed to facilitate a comparison of crystalline and amorphous ingredients. The flour used was bleached all-purpose Gold Medal from General Mills (Minneapolis, MN, USA).

Table 2-1 Properties of sucrose and sucrose replacers.

Sucrose or Sucrose Replacer	Initial physical form	Glycemic Index	Sweetness score	Laxative Threshold*	Source
Sucrose	Crystalline	68	1	-	Great Value
HFCS	Syrup	60-65	~1	-	Tate & Lyle
Amorphous Sucrose	Amorphous	68	1	-	Great Value
Allulose	Crystalline	~0	0.7	~30g/day	Tate & Lyle
Maltitol	Crystalline	35	0.8-0.9	30g/day	Alfa Aesar
Isomalt	Crystalline	9	0.45-0.65	-	Beneo
Benefiber	Amorphous powder	25	0	12g/day	GSK
Miralax	Crystalline	0	0	17g/day	Bayer
Fructooligosaccharide (FOS)	Amorphous powder	0	0.3-0.6	20g/day	Beneo
Isomaltooligosaccharide (IMO)	Amorphous Powder	35	0.5	30g/day	Vitafiber

(Chattopadhyay et al., 2014; Chen et al., 2001; Han et al., 2018; Nabors, 2012; Nutrition, 2000; O'Donnell et al., 2012; Suraphad et al., 2017; Woodbury et al., 2021; Zhang et al., 2016)
*Approximate values from FDA GRAS Reports.

2.3.2 Cookie formulation

The AACCI formula and method for wire-cut cookies 10-53.01 (1999) was used to prepare all cookies for sensory panel and physiochemical analyses. SRs replaced sucrose in a 1:1 ratio on a dry weight basis. A KitchenAid stand mixer was used to mix samples before dividing dough into four equal portions, which were then rolled on a cookie sheet to 6 mm, and cut into 5.7 cm diameter circles. Cookies were baked in a conventional oven for 9 minutes at 205°C. The cookies and cookie sheet were weighed before and after baking to calculate moisture loss (Kweon et al., 2009a). Height, weight, and length measurements of cookies were taken after 30 minutes of cooling. All cookies were stored for 48 hours at room temperature (22°C) in resealable, 1 quart plastic bags (GFS, Grand Rapids, MI, USA) before further physiochemical analysis and consumption by panelists.

Table 2-2 Ingredient formulation for wire-cut cookies made using the AACCI method (10-53.01).

	Weight (g)	
Ingredients	**AACCI formula**	**Adjusted formula[a]**
Flour	225	225.8
Sucrose or SR	94.5	94.5
Nonfat dry milk	2.3	2.3
NaCl	2.8	2.8
Sodium bicarbonate	2.3	2.3
Shortening	90	90
HFCS	3.4	3.4
Ammonium bicarbonate	1.1	1.1
Water	49.5	48.7

[a] Adjusted from AACCI formula to account for flour moisture content of 13.3% (wb).

2.3.3 Physiochemical Property Analysis

Starch Gelatinization

The starch gelatinization temperature (T_{gel}) of the starch in wheat flour in the presence of different sweetener solutions was measured using differential scanning calorimetry (DSC) using a method adapted from Allan et al. (2018). Sweetener solutions were made on a %w/w dry basis at 40%, 50%, and 60% for each sweetener. Considering the volume of the sweetener, water (20-40g) was added to 50 mL centrifuge tubes. The amount of sweetener needed to achieve the desired %w/w concentration was calculated and the actual weight of the sweetener was recorded before adding into the centrifuge tube. The sweetener-water solutions were then mixed with a Roto-Shake Genie (Bohemia, NY) until crystals were no longer visible. Higher concentration solutions were placed on a heating block (~5 min) set to 80°C to aid with crystal dissolution. Once

solutions were cooled and fully mixed, they were immediately used for starch gelatinization temperature analysis.

Samples were prepared by combining flour in a 1:2 ratio with DI water or sweetener solution in a centrifuge tube. Samples were vortexed until a slurry formed and then stored overnight at room temperature (~23°C). After overnight storage the samples were vortexed again, pipetted into a DSC pan (15-20mg), and hermetically sealed. The DSC pan was then placed in a Perkin Elmer DSC 4000 (Waltham, MA) along with an empty DSC pan for reference. Samples were heated from 10°C to 110°C at a rate of 10°C/min. Pyris software was used to calculate the onset temperature, peak temperature, area under the curve, and enthalpy (ΔH) of starch gelatinization from the thermograms. All samples were measured in triplicate, and the DSC was calibrated using indium.

Cookie color, physical appearance, and texture

Physical measurements of the cookies were taken 48 hours after cookies were baked. Cookie color was analyzed using the Color Companion app on the iPhone 7s camera. The top and bottom of four cookies were photographed in a Elviros light box, and L (lightness as %), b (yellow for positive and blue for negative), and a (red for positive and green for negative) values were recorded. Photographs of the cookies were taken in the light box using the iPhone 7s camera to document the qualitative differences in shape, color, spread, and surface cracking of the cookies.

Water activity of cookies at 25°C were also determined 48 hours after baking. Water activity was measured in triplicate using an AquaLab 4 TE (METER Group, Pullman, WA) calibrated using the manufacturer's specifications. A TA.XT2i texture analyzer (Texture Technologies, Scarsdale, NY, USA) was used to measure cookie hardness (N). A fixed span three-point bend rig (TA-92FS) with a knife blade (TA-42) and a cone probe (TA-15) were used.

2.3.4 Sensory Descriptive Analysis

The research protocol was approved as exempt by the Institutional Review Board at Purdue University (IRB-2020-607).

Sample Preparation

After cookies were baked following the AACCI wire-cut cookie method 10-53.01 (1999) and cooled for thirty minutes at room temperature on wire trays, samples were cut into approximately one-inch sections and placed in labeled 1 oz. sample cups with lids (GFS, Grand Rapids, MI, USA). Each cup contained two, one-inch cookie sections. Two sample cups were placed into a 1-quart resealable plastic bag (GFS, Grand Rapids, MI, USA). The plastic bags containing the samples and text instructions were placed in a cardboard box which was labeled with the participant number. During the experimental weeks, the participants received a total of eight samples, duplicates of four sample types. Boxes were allowed to sit for 48 hours before participant pick up at Purdue's Clinical Research Center, which allowed minimal person-to-person contact during the study protocol. This was to comply with social distance and Purdue Institutional Review Board requirements during the COVID-10 pandemic (study was conducted in early 2021).

Descriptive analysis Panel

Participants were recruited online utilizing the Saliva, Perception, Ingestion, and Tongues (SPIT) Lab participant database. Individuals were excluded if they had food allergies, lacked a full set of teeth, had braces or permanent retainers, or were not located in the local area. Panelists were recruited via online screener survey to determine if they met the study criteria. A secondary survey was sent to qualifying potential participants with additional details about the study and to gain information about their availability. A panel time was selected from potential participant availability and panelists available enrolled in the study. The panel was held using video conferencing (Zoom) to comply with 2020-2021 COVID-19 protocols. Samples were prepared and packaged 48 hours before consumption and contact-less sample pick up was implemented. Nine panelists were selected with an age range from 20 to 45, four females and five males. Panelists were trained on six attributes mostly focusing on texture (hardness, cohesiveness, pastiness, crumbliness, fracturability, and sweetness) (Table 2-3). The panel took place once a week for one hour for twelve weeks. The first nine weeks panelists were trained to a number of reference samples for each attribute on a 0 to 15 line scale. References and attribute descriptions were adapted from Spectrum® Intensity Scales which defines hardness, fracturability, cohesiveness, and sweetness (Lawless, 2010). Pastiness and crumbliness were additional attributes

added to the study as they have been previously defined by descriptive analysis panelists as important attributes to cookies (Laguna et al., 2012). Samples were presented in a randomized order and labeled with a three-digit code. The panel leader guided the group through the training, clarifying definitions and answering questions. After training, test samples using sugar replacers were evaluated in duplicate for all six attributes. Sensory evaluation data was collected using RedJade® (Redwood City, CA) on the panelist's personal computers.

Table 2-3 Descriptive analysis attributes, their description, and the references samples used for training.

Attribute	**Description**	**References**
Hardness	The force to attain a given deformation	Marshmallow -1 Gluten free cookie -2
Fracturability	The force with which the sample breaks	Graham Cracker - 4.2 Gingersnap – 8
Cohesiveness	The degree to which sample deforms rather than crumbles /breaks/cracks	Hostess coffee cake – 1 Seedless Raisins – 10 Gum - 15
Pastiness	The degree to which a paste forms in the mouth	Saltine - 14 Chessman - 7
Crumbliness	The degree to which a sample breaks apart in the mouth	Nature valley bars-13 Starburst - 1
Sweetness	The amount of sweet sensation	Ritz Cracker – 4 Boudreaux Cookie – 12.5

References: (Laguna et al., 2012; Lawless, 2010)

2.3.5 Statistical Analysis

To evaluate the effect of sucrose replacers and sucrose on wire-cut cookie baking properties (T_{gel}, color, spread, moisture loss, a_W, and hardness) a single factor ANOVA and Tukey post hoc test ($\alpha = 0.05$) via SAS 9.4 statistical software (SAS Institute, Cary, NC, USA) were utilized. Sensory descriptive analysis data were analyzed in Python 3 and SAS in Jupyter Lab

(https://jupyter.org/). Mixed linear models were used with each subject as a repeated factor, with the covariance structure set to compound symmetry. The Kenward Roger approximation was used for estimating degrees of freedom. To determine differences in intensity ratings among samples,, least square means were tested and p-values adjusted using the Tukey-Kramer approach. Pearson correlations were created using Origin Pro (Northhampton, Massachusetts, USA) and used to understand the strength of relationships between the different variables measured in this study. Principal Component Analysis (PCA) was conducted using OriginPro 2020 (Northhampton, Massachusetts, USA), which was also used to generate boxplots. To conduct PCA, default settings were used with the addition of checking the scores plot box under the plots tab.

2.4 Results and Discussion

2.4.1 Effects of sucrose and sucrose replacers on wheat starch T_{gel} of flour

The ability of sucrose to increase the starch gelatinization temperature (T_{gel}) of wheat starch more than other sweeteners has made it difficult to replace in low moisture baked goods (Allan et al., 2018; BeMiller, 2019; Woodbury et al., 2021). The extent of starch gelatinization can have an effect on the final texture of cookies and is an important parameter to study when investigating sucrose replacement. The T_{gel} of wheat starch in water is ~58.55 °C. The presence of sucrose elevates the T_{gel}, dependent on the concentration of sucrose, for example to 79.3°C at 40%w/w sucrose solution and 96.7°C at 60% w/w sucrose solution (Table 2-1). The effects of sucrose replacement using a variety of different SRs at three concentrations on the T_{gel} of wheat starch in flour are shown in Figure 2-1 and Table 2-4. While increasing the concentration of all sweeteners increased the T_{gel} of starch, the extent of T_{gel} elevation varied by sweetener type. Allulose and HFCS elevated the T_{gel} less than all other SRs studied, and significantly less than sucrose. In contrast, FOS and Miralax elevated the T_{gel} of wheat starch more than sucrose and other SRs, with differences in T_{gel} increasing as the SR concentration increased. In wire-cut cookies, the sucrose concentration is 66%, making the 60%w/w sweetener concentrations most interesting in reference to the effects sucrose replacement on starch gelatinization in cookie baking (Kweon et al., 2009a). At 60% w/w sweetener solutions, Benefiber, maltitol, and IMO had no significant difference in T_{gel} compared to sucrose. Miralax and FOS elevated the T_{gel} of starch significantly more than sucrose at 60%w/w. Isomalt was not soluble at 60%, but the T_{gel} of starch in the presence of

isomalt was not statistically different from sucrose at 50%. In the presence of 60% sucrose solution, T_{gel} was 97°C, and in the presence of 60% Miralax the T_{gel} was 105°C, which was the highest T_{gel} elevation in this study. The T_{gel} of wheat starch in the presence of allulose and HFCS was lower than the T_{gel} in the presence of any other sweetener used in this study at all concentrations. At 40% and 50% concentrations, all oligosaccharides and polymer-based sucrose replacers elevated the starch T_{gel} to the same extent as sucrose (there were no significant differences in the T_{gel}s of these samples collected at the same sweetener concentration). At the 60% concentrations, Miralax and FOS increased starch T_{gel} more than sucrose while IMO and Benefiber increased starch T_{gel} to the same extent as sucrose.

Table 2-4The effect of sucrose replacers on Tgel (°C) of wheat starch in flour compared to sucrose.

	40% w/w	50% w/w	60% w/w
Sweetener Type	**T_{gel} Onset (°C)**	**T_{gel} Onset (°C)**	**T_{gel} Onset (°C)**
Sucrose	77.86 ± 0.38^{BCc}	86.23 ± 0.80^{BCb}	96.66 ± 2.2^{Ca}
Benefiber	76.2 ± 1.59^{CDc}	86.43 ± 0.84^{BCb}	99.35 ± 0.6^{BCa}
Isomalt	80.05 ± 1.71^{A} Bb	88.67 ± 0.33^{AB} Ca	-
Miralax	81.02 ± 0.41^{ABc}	92.75 ± 1.17^{ABb}	106.91 ± 1.61^{Aa}
FOS	82.11 ± 0.92^{Ac}	91.9 ± 0.36^{Ab}	103.96 ± 0.49^{ABa}
Maltitol	79.19 ± 1.42^{ABC} c	86.16 ± 1.65^{Cb}	98.02 ± 1.12^{BCa}
IMO	79.28 ± 0.94^{ABC} c	87.32 ± 1.53^{Ab}	98.92 ± 2.53^{BCa}
Allulose	70.01 ± 0.44^{Eb}	75.47 ± 1.83^{Dab}	81.85 ± 0.54^{Da}
HFCS	72.98 ± 0.6^{DEb}	78.61 ± 1.6^{Db}	86.04 ± 0.4^{Da}
Control	58.55 ± 0.37^{F}	58.55 ± 0.37^{E}	58.55 ± 0.37^{E}

Uppercase letters indicate statistical differences (α=0.05) between sweetener types for a specific concentration. Lowercase letters indicate statistical differences (α=0.05) between different concentrations of the same sweetener.

In general, these results are consistent with previous studies that have documented the effects of different sweetener types and concentrations on the T_{gel} of starch, some of which used isolated starch while this study used flour. Mono-saccharides have been shown to increase starch T_{gel} to a lesser extent than di-saccharides generally due to their size and weight, but differences in extent of T_{gel} increase between monosaccharides was observed and attributed to the number of intermolecular interactions with starch (Allan et al., 2018). Sugar alcohols have been shown to have a greater effect on T_{gel} elevation than their counterpart sugars, attributed to their ability to form more hydrogen bonds (water and starch), and in this study isomalt and maltitol elevated the T_{gel} of wheat starch as much as sucrose at all concentrations, with the exception of isomalt at 60% (this exceeded the solubility threshold of isomalt)(Allan et al., 2018). The effects of allulose, an epimer of fructose, on starch T_{gel} were less than that of HFCS, a syrup of glucose and fructose. Of the mono- and di-saccharides included in this study, isomalt and maltitol are the most likely

candidates for successful cookie reformulation strategies when considering the starch gelatinization parameter. During baking, the temperature of cookies has been reported in literature from a range of 115°C to 146°C making it difficult to pinpoint an exact target starch T_{gel} to target for reformulation strategies (Hoseney, 1994; Walker et al., 2012). A saturated sucrose solution has been shown to increase the T_{gel} of wheat starch to 103.8°C, a temperature less than the temperature range cookies reach in the oven (Allan et al., 2018). Starch gelatinization is also dependent on moisture conditions, which are low in cookies. Before baking, the moisture content of dough is 11-30% while after baking the moisture content of cookie is 1-5% (Pareyt et al., 2008). Isolated starch in low moisture conditions (<30%) have elevated T_{gel} above the reported cookie temperature range (Donmez, Pinho, Patel, Desam, & Campanella, 2021;Renzetti, van den Hoek, & van der Sman, 2021). Without an identified target starch T_{gel}, the current method for identifying potential replacements is finding sucrose replacers that elevate starch T_{gel} as much as or more than sucrose.

The larger molecular weight oligosaccharides and polymer-based sucrose replacers (FOS, IMO, Benefiber, and Miralax) elevated the starch T_{gel} as much or more than sucrose (Figure 2-1). In this study, Benefiber did not increase the T_{gel} more than sucrose which is not consistent with the reporting in Woodbury et al. (2021). This discrepancy between studies was attributed to differences in the preparation of the solutions, where Woodbury et al. prepped solutions on a dry weight basis and solutions and in this study, solutions were prepped as is. Other large polymers, such as polyethylene glycol, have also increased starch T_{gel} at high concentrations(Martínez-Cervera et al., 2013). This increase in T_{gel} at high concentration of polymer could be linked to their intermolecular interactions (hydrogen bonding) with starch and/or their “antiplasticizing” effect on water (Allan et al., 2018; van der Sman et al., 2019). Based on T_{gel} elevation, all of the oligosaccharide and polymer-based ingredients have potential for reducing sucrose in low moisture cookies at high concentrations.

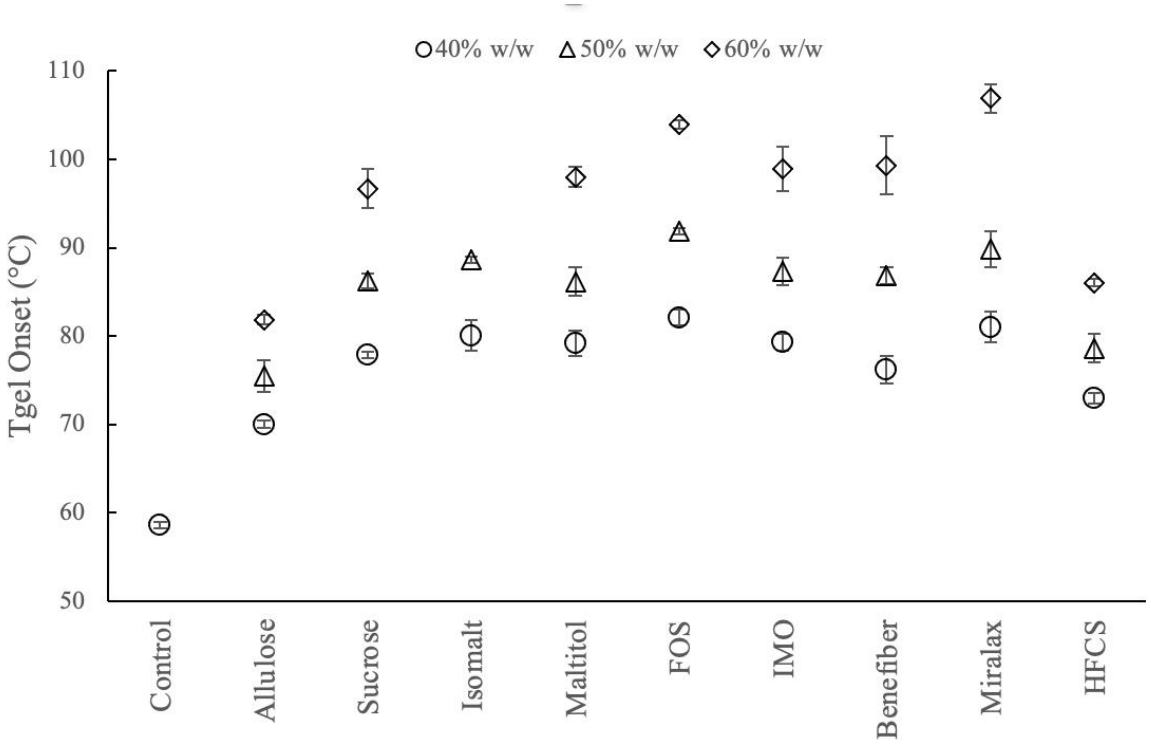

Figure 2-1Effects of three sweetener concentrations (40%, 50%, and 60%w/w) on the Tgel of flour.

Table 2-5 Effects of sucrose replacement in AACCI wire-cut cookies properties with 1:1 replacement on a_W, moisture loss, cookie dimensions (cm), and extent of browning.

Sweetener Type	a_w	% Wt. Loss	Cookie Dimensions (cm)			Top Surface Color			Bottom Surface Color		
			Width	Height	Spread	a	b	L	a	b	L
Allulose	0.5227±0.0084^{d}	9.0±0.8^{abcd}	6.2±0.05^{f}	1.1±0.03^{ef}	1.4±0.03^{cd}	-3.5±1.4^{f}	61.6±1.3^{a}	87.2±1.1^{abc}	2.6±0.6^{d}	54.3±3.6^{de}	84.5±0.1^{bc}
HFCS	0.6815±0.0097^{b}	10.4±0.3^{a}	6.48±0.08^{de}	1.2±0.03^{cde}	1.4±0.04^{d}	1.7±0.5^{bc}	42.6±2.1^{c}	85.9±0.8^{bc}	18.8±1.1^{b}	61±1.0^{abc}	73.8±1.6^{d}
Sucrose	0.4048±0.0110^{e}	8.9±1.5^{abcd}	6.6±0.1^{cd}	1.2±0.1^{c}	1.4±0.08^{d}	0.18±2.07^{cde}	33.4±3.0^{de}	87.2±1.1^{abc}	2.6±0.6^{d}	54.3±3.6^{de}	84.5±0.1^{bc}
Amorphous Sucrose	0.5378±.0035^{d}	9.5±0.7^{abc}	6.6±0.03^{cd}	1.1±0.05^{de}	1.5±0.06^{cd}	1±1.1^{bcd}	38.1±1.45^{cd}	88.2±1.0^{ab}	9.2±2.5^{c}	55.7±3.1^{cd}	77.0±2.1^{e}
Isomalt	0.5791±0.0109^{c}	7.5±0.9^{cde}	7.0±0.3^{b}	1.2±0.08^{cde}	1.5±0.15^{c}	-1.5±0.2^{ef}	28.4±2.2^{e}	87.7±1.0^{ab}	4.9±2.0^{cd}	53.4±2.2^{de}	82.7±1.7^{cd}
Maltitol	0.5294±0.0202^{d}	8.1±0.4^{bcd}	6.7±0.1^{c}	1.2±0.06^{bcd}	1.4±0.08^{cd}	-2.1±0.9^{ef}	37.8±2.6^{cd}	87.0±1.5^{abc}	4.8±1.4^{e}	56.4±3.4^{cd}	88.4±1.2^{a}
IMO	0.3850±0.0068^{e}	9.8±0.8^{ab}	7.0±0.1^{b}	1.0±0.05^{fg}	1.7±0.1^{b}	2.8±0.6^{b}	51.0±5.5^{b}	84.8±1.1^{c}	17.0±0.4^{b}	65.9±2.3^{a}	76.1±0.2^{ef}
FOS	0.3502±0.0027^{f}	9.9±0.3^{ab}	7.5±0.06^{a}	0.98±0.05^{g}	1.9±0.09^{a}	15.4±0.6^{a}	66.7±1.0^{a}	75.7±1.4^{d}	25.9±1.5^{a}	64.0±2.0^{ab}	69.2±1.7^{g}
Benefiber	0.5985±0.0052^{c}	6.8±0.8^{de}	6.4±0.08^{ef}	1.9±0.1^{a}	0.8±0.05^{f}	-0.99±0.75^{de}	41.2±2.1^{c}	88.0±0.8^{ab}	8.3±0.8^{c}	57.4±1.7^{bcd}	80.5±0.8^{d}
Miralax	0.7643±0.0031^{a}	5.4±0.4^{e}	5.9±0.06^{g}	1.3±0.06^{b}	1.2±0.06^{e}	1.2±0.7^{bcd}	30.8±2.3^{e}	86.3±1.2^{abc}	2.4±1.3^{d}	47.9±3.1^{e}	85.2±1.2^{b}

2.4.2 Effects of sucrose and SRs on wire-cut cookie properties

The physical properties determined for the wire-cut cookies made using different SRs are reported in Tables 2-5 and 2-6. These included percent weight loss, a_w, cookie dimensions (width, length, and height), top surface color, bottom surface color, and hardness.

The majority of SRs resulted in cookies with higher a_{ws} than cookies made with sucrose (0.40 a_w), except for FOS (0.35 a_w) and IMO (0.38 a_w). The cookies with the highest a_ws were made with HFCS (0.68 a_w) and Miralax (0.76 a_w). While there is not a linear correlation between moisture content and a_w (many foods with amorphous structural components exhibit a type 2 sigmoidal relationship between moisture content and a_w) higher moisture contents tend to increase a_w. The amount of weight (moisture) lost in the cookies ranged from 5.4% (Miralax) to 10.4% (HFCS), with sucrose-based cookies losing 8.9% weight during baking. Cookies made with Miralax had the highest a_w and the lowest percent moisture loss compared to all the SRs and sucrose. The a_W and % moisture loss of the sucrose and sucrose replacers was not significantly correlated to according to Pearson correlations; however, an outlier (HFCS) was identified (Figure 2-2). Upon removing HFCS, a strong negative correlation between a_W and % moisture loss during baking was shown (Figure 2-3).

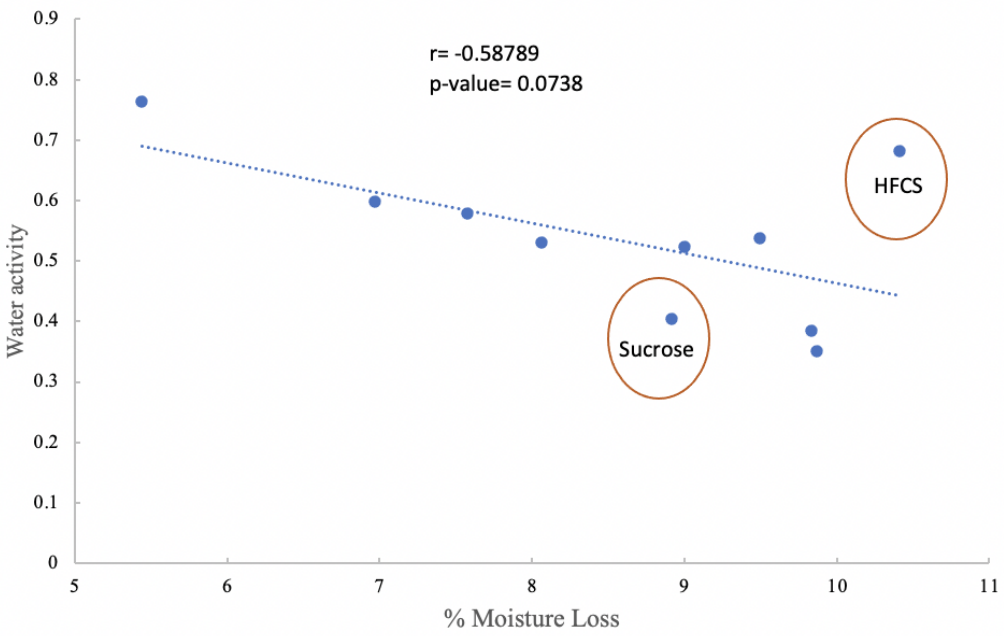

Figure 2-2 Pearson correlation of water activity and % moisture loss of sucrose and sucrose replacers.

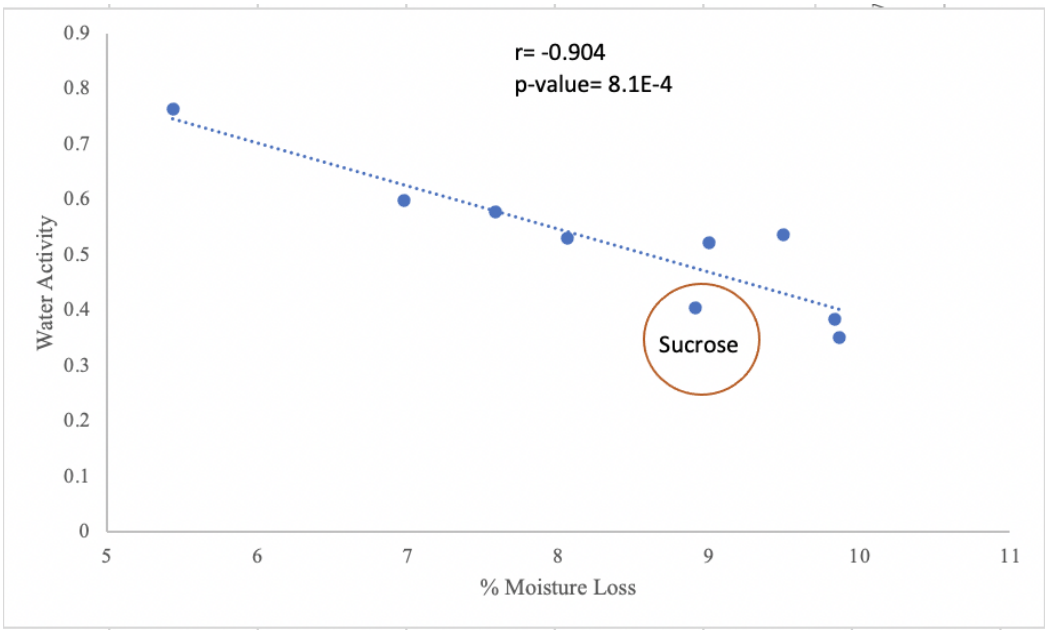

Figure 2-3 Pearson correlation of water activity and % moisture loss of sucrose and sucrose replacers after removing HFCS.

In terms of cookie diameters (Table 2-5 and Figure 2-4), cookies made with maltitol and HFCS were statistically similar to those made with sucrose in length, width, and height. Overall,

FOS cookies displayed the lowest height (0.98 cm) and the largest length/width (7.5 cm) indicating the largest spread, while Benefiber and Miralax cookies displayed the largest height (1.9 and 1.3 cm) and the lowest length/width (6.2 and 5.9 cm). Cookies made with amorphous sucrose were similar to those made with crystalline sucrose in width and length, but not height. Miralax and isomalt cookies had heights statistically similar to sucrose cookies, but not length and width. In cookies, the amount of cookie spread is an indicator of quality, and a higher spread ratio (length/height) is desirable. Cookie spreading has been related to many factors, gluten interactions, sucrose dissolution during baking, and dough hydration (Gaines, 1998; Kweon et al., 2009a). The high concentration of sucrose in wire-cut cookies causes dough setting during baking to occur at a higher temperature due to the increase in sucrose solution concentration as crystalline sucrose in the dough dissolves, and the sucrose solvent plasticizes less gluten than water alone (Pareyt et al., 2009). The initial physical state of the sucrose replacers used were not all crystalline. Amorphous sucrose, Benefiber, FOS, and IMO all had an amorphous initial physical state. Benefiber and Miralax cookies could have had a more established gluten network preventing expansion and collapse during baking. It is important to note that Benefiber and Miralax cookies, which demonstrated the most spread, also had the lowest amount of moisture loss. The altered water dynamics and/or molecular mobility in doughs with different SRs at the same moisture content could change the degree of gluten development in the dough (Woodbury et al., 2021).

Texture measurements were taken to determine the force required to penetrate and break the cookies formulated with sucrose and SRs (Table 2-6). Cookies formulated with Benefiber and FOS maxed out the load cell (6kg) for the 3-point bend method. The maximum force to break sucrose cookies was 3302N. The maximum force to break allulose (2602 N) and amorphous sucrose (2841 N) cookies were statistically similar to sucrose cookies. Overall, cookies containing smaller molecular weight SRs required less force to break than cookies made with larger MW SRs, which has been previously observed (Woodbury et al., 2021). FOS and IMO cookies displayed decreased a_w values and high moisture loss and were statistically higher than sucrose cookies in maximum force to break. The higher moisture contents likely created conditions that supported more gluten development in Miralax and Benefiber cookies, and the gluten could have made Miralax and Benefiber cookies harder than the other cookies in this study (wherein the lower moisture contents could have reduced gluten development).

Table 2-6 Texture analysis on AACCI wire-cut cookies made with sucrose replacers (1:1 replacement) for hardness (N).

Sweetener Type	3-point bend	45° cone (TA-15)
	Maximum Force (grams)	Maximum Force (grams)
Allulose	2602±270de	354±28^{cd}
HFCS	1641±40^{g}	312±23^{cd}
Sucrose	3302±229^{c}	483±157^{c}
Amorphous Sucrose	2841±161^{cd}	345±174^{cd}
Isomalt	1937±72^{fg}	427±20^{c}
Maltitol	2187±263^{ef}	291±29^{cd}
IMO	6117±11^{a}	2500±68^{a}
FOS	>6117	70±28^{d}
Benefiber	>6117	406±259^{c}
Miralax	5183±105^{b}	802±74^{b}

The color of cookies formulated with sucrose and SRs was analyzed via L (0 to 50 dark and 50 to 100 light), a(+red, -green), and b(+yellow, -blue) values, and pictures were taken for visualization (Figure 2-4 and Table 2-5). Cookies formulated with different SRs had different colors after baking. Wire-cut cookies formulated with sucrose displayed high L values due to the nonreducing nature of sucrose(Kweon et al., 2009b). Of the SRs utilized in this study, none were statistically lighter than sucrose for top surface color. Cookies formulated with FOS were significantly darker on the top and bottom than sucrose cookies and other cookies with SRs. Allulose, which appears dark in Figure 2, was not significantly different in lightness from sucrose, but displayed b values (yellow) higher than sucrose.

Figure 2-4 Top(A), bottom (B), and side view (C) of wire-cut cookies with various sucrose replacements (from left to right): sucrose, Miralax, Benefiber, maltitol, isomalt, IMO, allulose, FOS, HFCS, and amorphous sucrose.

2.4.3 Effect of sucrose and SRs on texture perception of wire-cut cookies

The texture perception of sucrose and sucrose replacers in wire-cut cookies was investigated using a descriptive analysis panel. Panel participants rated hardness, fracturability, cohesiveness, sweetness, pastiness, and crumbliness intensity on a 1-15 scale and attribute intensity means can be found in Table 2-7 and Figure 2-5 (Lawless, 2010; Laguna et al., 2012). Panel performance was not optimal, as seen in the variability in ratings within each cookie type. This may be due in part to the remote nature of the study, which is not typical in the training of descriptive analysis panels. As a result, differences in mean ratings need to be relatively large in order to be significant, considering the small panel size and relatively high variability in responses. Nonetheless, the use of linear mixed models with repeated measures allows for some comparisons among the cookie ratings.

For crumbliness, the overall effect was not significant, therefore, there were no significant differences between sucrose and SRs at $\alpha = 0.05$. Crumbliness showed poor panel agreement, with displayed mean values between 8.1-10.7. Cohesiveness was difficult for panelists to grasp during training, leading to variability in responses and poor panel agreement. There was a significant overall effect for cohesiveness, but there were no differences between sucrose and sucrose replacers. For hardness intensity, ratings had a significant overall effect at $\alpha = 0.05$. Compared to sucrose cookies, isomalt cookies were rated as significantly less hard, and this also reflected in the analytical measurements that show these cookies took significantly less force to break in the 3-point bend force test (Table 2-6). Benefiber, FOS, and IMO cookies were rated as significantly harder than sucrose cookies. Hardness ratings for other cookies with sucrose replacers displayed some variability but were not significantly different from sucrose cookies. Fracture intensity ratings had a significant overall effect. There was a significant difference in fracturability intensity scores of sucrose cookies compared to FOS, IMO, and Benefiber. FOS, IMO, and Benefiber cookies had greater fracturability intensity in comparison to sucrose cookies. This aligns with the force it took to break the cookies in the 3-point bend method (Table 2-6). The overall effect for pastiness was significant at $\alpha = 0.05$. Pastiness was not significantly different between the sucrose cookies and cookies formulated with SRs. FOS cookies were significantly lower in pastiness intensity scores than HFCS and allulose cookies. Sweetness intensity was also evaluated and had a significant overall effect. All cookies formulated with sucrose replacers except for amorphous sucrose cookies had significantly lower sweetness intensity compared to sucrose cookies. Overall,

FOS, IMO, and Benefiber cookies displayed significantly higher fracturability and hardness ratings aligning with the analytical measurements that show these cookies as significantly harder to break (Table 2-6).

The remote nature of this panel made it more difficult for the panel leader to facilitate discussion amongst the participants. Variability in panelist engagement with the discussion and activities could account for the high variability and lack of statistical significance across many of the traits of the cookies containing SRs and sucrose. This variability made it difficult to identify the cookies containing sucrose replacers that were most similar to sucrose-containing cookies in perceived texture relying solely on the descriptive sensory panel results.

Table 2-7 Descriptive analysis results for hardness, cohesiveness, sweetness, pastiness, and crumbliness on a 1-15 scale.

Sweetener Type	Hardness	Fracturability	Cohesiveness	Sweetness	Pastiness	Crumbliness
Sucrose	3.2±1.1	4.2±2.8	5.6±1.9	8±2.4	8.1±1.8	8.1±2.5
HFCS	3.2±1.5	4.1±2.2	6.3±3.3	4.2±2.2	9.4±2.3	8.3±3.5
Amorphous Sucrose	4.7±1.3	4.4±1.5	5.8±2.4	7.8±2.6	8.4±2.0	9.3±2.8
Benefiber	8.9±2.3	6.1±1.9	4.9±2.8	3.1±2.7	7.0±3.6	9.8±3.8
Isomalt	2.6±1.0	3.5±3.6	4.4±3.4	5.1±2.7	8.8±2.8	8.7±4.1
Miralax	2.8±1.6	4.7±3.0	4.7±2.9	2.1±1.6	7.2±3.6	9.2±3.3
FOS	7.5±2.0	6.6±1.9	5.5±3.9	3.4±2.2	6.1±2.0	8.5±3.6
Maltitol	3.3±1.6	3.6±2.6	5.4±2.6	6.6±2.7	8.6±2.0	10.1±2.1
IMO	7.9±1.7	6.7±2.1	4.7±2.2	3.1±2.0	6.5±3.0	10.7±2.6
Allulose	4.4±2.0	4.2±2.4	6.6±0.8	4.1±2.2	9.2±2.0	8.3±1.6

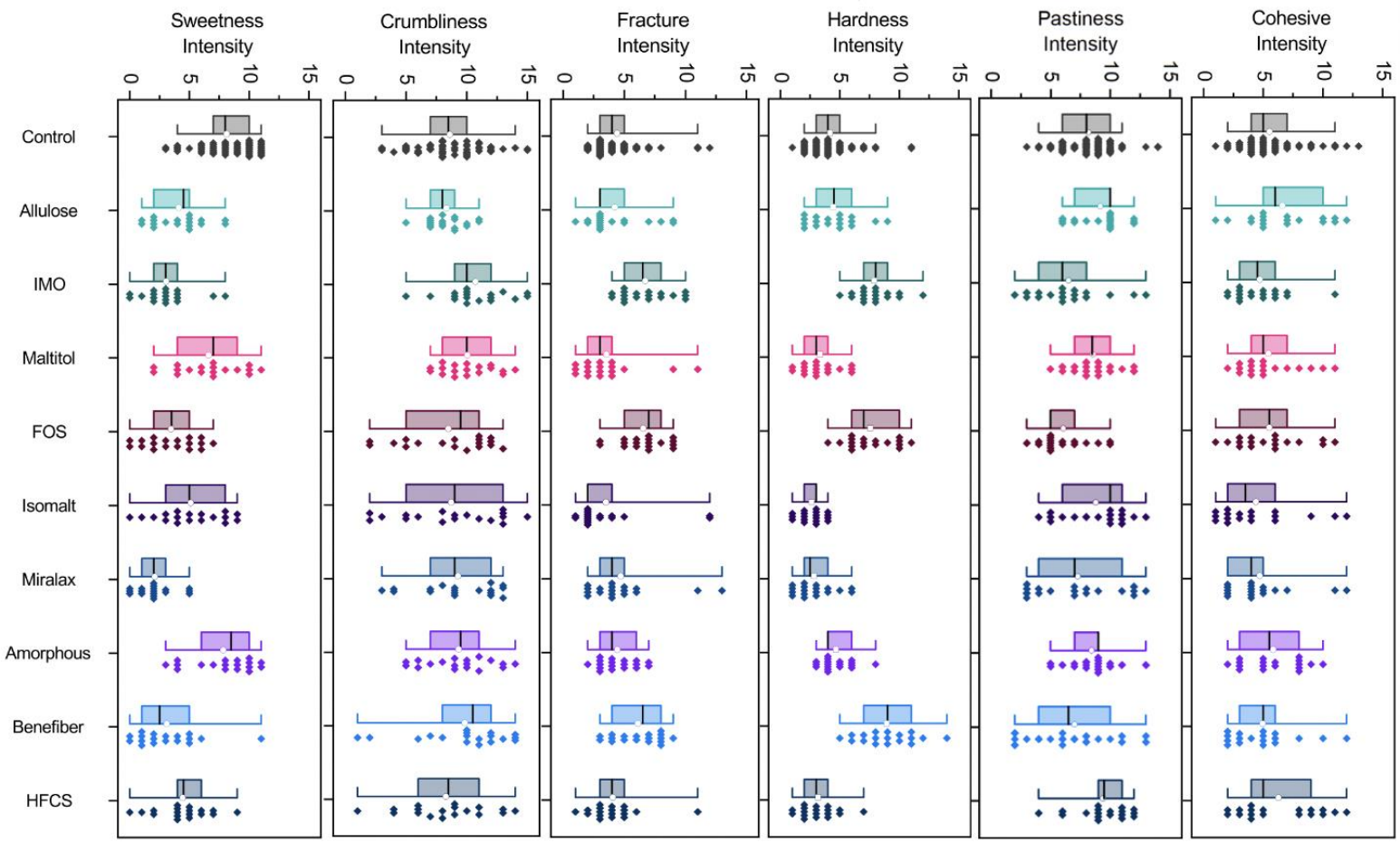

Figure 2-5 Intensity scores for the six attributes on a 1 – 15 intensity scale of ten different sucrose replacers.

2.4.4 Principal Component Analysis

PCA plots were created to determine the relationship between intensity ratings, T_{gel}, and cookie properties. The model utilized T_{gel} measured in 50% w/w solutions to avoid excluding isomalt which is not soluble at 60% w/w. A series of scores and loading plots with an increasing number of components is present in Figure 2-6. A large loading value (negative or positive) indicates a correlation (negative or positive) within a given principal component. A large negative value negatively correlates to a large positive value, but positively correlates with other large negative values. Loading values were calculated from eigenvalues and eigenvectors and used to determine which of the variables contributed to a principal component and if the variables were negatively or positively correlated (Gokulakrishnan et al., 2006). Scores plots (Figure 2-6) demonstrated which sucrose replacers were most similar to sucrose based on the variables inputted. Vectors in the scores plot show the direction and degree of correlation between the different attributes being analyzed.

The first plot was built using the data from the descriptive analysis panel (hardness, fracturability, cohesiveness, pastiness, and crumbliness) and explained 85.4% of the data when combining both PC-1 and PC-2 (Figure 2-6A). From the loading plot, hardness and fracturability ratings had a strong positive correlation in PC 1. FOS, Benefiber, and IMO cookies were all rated as significantly harder than sucrose cookies and can be found on the right side of this PCA plot. Cohesiveness has a strong positive correlation in PC 2. Allulose had the highest median score for cohesiveness intensity while isomalt had the lowest. In PC 1, pastiness had a negative correlation. Crumbliness had a slight positive correlation in PC 1 and a slight negative correlation in PC 2. Overall, in the first PCA plot, mono- and disaccharides were closely related in PC 1 but were separated by cohesiveness in PC 2. Excluding Miralax, the larger molecular weight sucrose replacers were closely related in PC 1.

The second PCA plot was built using the cookie parameter and T_{gel} data (T_{gel}, force to break the cookies, % moisture loss, a_W, and spread) and explained 76.91% of the data (Figure2-6B). T_{gel} had a strong positive correlation in PC 2. Allulose and HFCS shown at the bottom of PC 2 had the lowest T_{gel}. In PC 1, spread an % moisture loss had strong positive correlations while force and water activity had negative correlations. The negative correlation between water activity and moisture loss is consistent with the Pearson correlations in Figure 2-3. The oligosaccharides were separated in PC 1 from the high molecular weight polymers due to spread and moisture loss. FOS

displayed the highest spread and can be found on the far right of the PCA, while Benefiber and Miralax had the lowest spread (Table 2-4). Mono- and disaccharides were grouped similarly in PC 1 because of their similar spread and moisture loss in cookies but separated in PC 2 with monosaccharide solutions increasing the T_{gel} less than disaccharides.

The final PCA plot combined the sensory and physical cookie data (T_{gel}, hardness, fracturability, cohesiveness, pastiness, force, moisture loss, water activity, and spread) to determine the relationship between all cookie parameters measured (Figure 2-6C). Overall, 69.38% of the variability of the data was explained by this PCA plot. Due to its lack of overall significance, crumbliness was left out of this plot. In PC 1, hardness and fracturability had the strongest positive correlations. Pastiness and water activity had a strong negative correlation in PC 1. In PC 2, spread and moisture loss had a strong positive correlation and force, and water activity had a strong negative correlation. The two oligosaccharides, FOS and IMO, were grouped closely in PC 1 and PC 2. FOS and IMO cookies has similar moisture loss and spread in PC 2 and were both rated as significantly higher hardness and fracturability intensity compared to sucrose in PC 1. Benefiber and Miralax were close in PC 2 due to their low spread but were separated in PC 1 by their hardness and fracturability intensity scores. In this PCA plot, mono- and disaccharides were grouped close together in PC 1 and PC 2. Isomalt was separated from sucrose in PC 1 due to its low hardness and fracture intensity scores. Maltitol, HFCS, amorphous sucrose, and allulose were all present in the upper left quadrant of the PCA with sucrose, indicating these sucrose replacers were most similar to sucrose in terms of the nine factors analyzed in this plot.

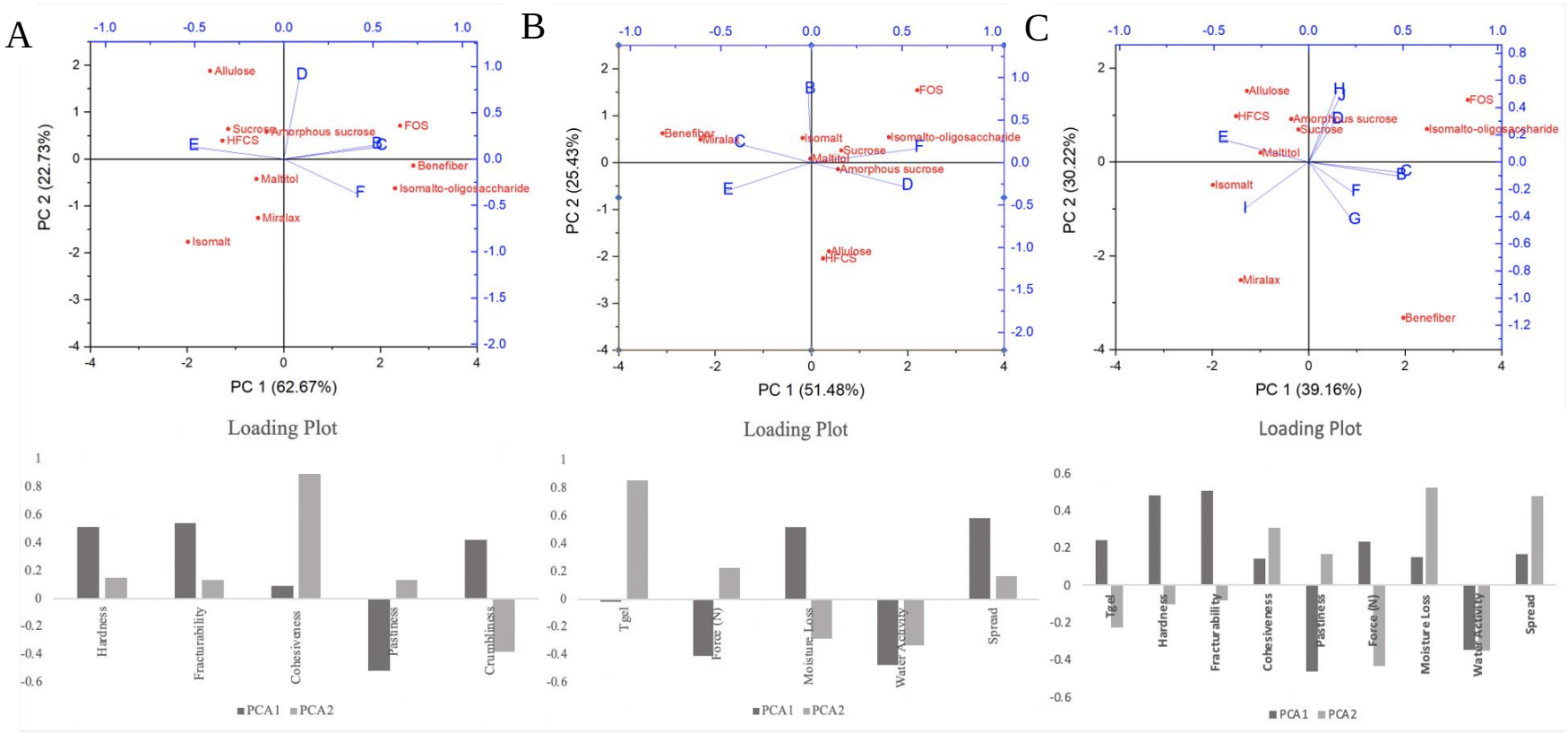

Figure 2-6 Principal component analysis was used to make scores plots for the first and second principal components (PC-1 and PC-2) with the corresponding loading plots.

2.5 Conclusions

A study to investigate effects of 10 SRs on wheat starch thermal properties, wire-cut cookie formulation, and sensory descriptive analysis of cookie texture was performed. The starch T_{gel} increased as the concentration of SRs and sucrose increased significantly relative to the control. At 60% w/w solutions, Benefiber, maltitol, and IMO increased T_{gel} to the same extent as sucrose while Miralax and FOS increased T_{gel} significantly more than sucrose. In term of baking performance, amorphous sucrose, maltitol, and allulose performed most similar to sucrose. Descriptive analysis intensity scores displayed no significant differences in crumbliness, cohesiveness, and pastiness between SRs and sucrose formulated wire-cut cookies. Fracture intensity for FOS, IMO, and Benefiber cookies was significantly higher compared so sucrose and isomalt cookies were significantly less hard than sucrose cookies. Starch T_{gel}, hardness, and fracturability displayed negative correlation to moisture loss in cookies while cohesiveness and moisture loss displayed a strong positive correlation. Overall, the large MW SRs decreased T_{gel} as much or more than sucrose, required the most force to break, and had high fracture intensity ratings. Principal component analysis (PCA) related SRs effect on starch gelatinization, cookie baking properties, and descriptive analysis intensity scores, and indicated the mostly likely candidates for use in reduced sugar cookies are maltitol, allulose, HFCS, and amorphous sucrose. HFCS and amorphous sucrose are considered "added sugar" on food labels and have similar glycemic response to sucrose. To achieve a lower added sugar in low moisture baked goods, maltitol and allulose are better candidates as they are not considered for "added sugar" on food labels and have low glycemic index response. Maltitol and allulose show promise as sucrose replacers in low-moisture baked goods based on their cookie baking performance, influence on starch thermal properties, perceived cookie texture, and does not contribute to "added sugar" label claims.

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CHAPTER 3. SUMMARY

Consumer demand for products, especially baked goods, formulated with low amounts of added sugar has driven research on sugar, specifically sucrose, replacement strategies. This demand is due to the nutritional implication of over-consumption of added sugars, with baked goods being a primary source of added sugars in the American diet. These strategies revolve around replacing sucrose with sugar alcohols and dietary fiber but struggle to meet consumer acceptability in terms of texture and flavor due to the long-standing use of sucrose in baked goods. Current sucrose replacement strategies aim to find sucrose replacers with similar physicochemical properties to sucrose and study their interactions with other baked good ingredients. Information on how a diverse set of SRs impact the texture perceived by consumers and how they interact with wheat flour components is limited. This work aimed at providing further understanding of the impact SRs have on texture of low-moisture baked goods through investigation of cookie ingredient interactions and texture perceived by the consumer.

The second chapter of this research investigated 9 SRs (high fructose corn syrup (HFCS), amorphous sucrose, maltitol, allulose, isomalt, Benefiber, Miralax, fructooligosaccharides (FOS), and isomalto-oligosacchrides (IMO)) and their effects on wheat starch thermal properties, wire-cut cookie formulation, and sensory descriptive analysis of cookie texture. Starch thermal properties were measured using differential scanning calorimetry and reported as onset starch gelatinization temperature T_{gel}. Wire-cut cookies were formulated with SRs and several parameters were recorded (% moisture loss, width, height, length, color, texture, and a_w). Through relation of the variables measured, maltitol and allulose were identified as the most likely candidates for reformulation in reduced sugar cookies.

Future Work

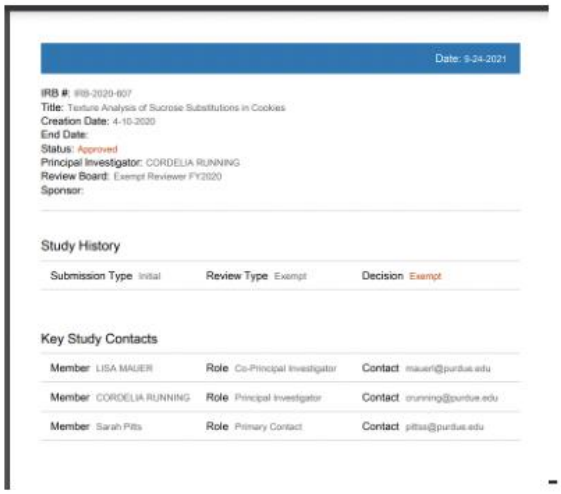
While this work made progress in identifying potential sucrose replacers for application in low-moisture baked goods, it was limited to 9 sucrose replacers and does not begin to cover the full complexity of low-moisture baked good systems. The remote nature of this study could be seen as a limitation in respect to the way descriptive analysis panels have been done in the past. Controlling the environment panelists are in has been the standard for descriptive analysis panels

to control the potential for environmental variability. In this research, panelists were in their home environment when they were testing samples, mimicking how they would be eating these products as a consumer. Allowing panelists to sample products in their home environment could be a more realistic way to understand differences between consumers in the future.

This study focused on full replacement of sucrose, but partial replacement is also a common strategy. Other studies have reported similar liking of partially replaced sucrose with sucrose replacers in comparison to sucrose. The mixture of different sucrose replacers to replace sucrose in cookies has not been fully investigated. Based on this research, it may be interesting to mix oligosaccharides, like FOS and IMO, with allulose and maltitol. This would increase the dietary fiber in products but also maintain parameters similar to that of sucrose. There is potential in optimization of cookie formulation through mixing different types of sucrose replacers.

Current research in carbohydrate chemistry has led to the discovery and/or development of novel sugars. As novel carbohydrates are found or derived, new studies to investigate their physicochemical properties, and their potential as sucrose replacers, is important. Physicochemical analysis and investigation into effects on starch thermal properties of these novel sugars will allow predictions to be made on their ability to replace sucrose in low-moisture baked goods.

APPENDIX A. DESCRIPTIVE ANALYSIS PANEL



Date: 9-24-2021

IRB #: IRB-2020-607
Title: Texture Analysis of Sucrose Substitutions in Cookies
Creation Date: 4-10-2020
End Date:
Status: Approved
Principal Investigator: CORDELIA RUNNING
Review Board: Exempt Reviewer FY2020
Sponsor:

Study History

Submission Type	Review Type	Decision
Initial	Exempt	Exempt

Key Study Contacts

Member LISA MAUER	Role Co-Principal Investigator	Contact mauerl@purdue.edu
Member CORDELIA RUNNING	Role Principal Investigator	Contact crunning@purdue.edu
Member Sarah Pitts	Role Primary Contact	Contact pittss@purdue.edu

and the Principal Investigator may be the same. The Primary Contact must be a current Purdue University faculty, staff, postdoc, or student and must have a role as Key Personnel on the study.

Once the name is selected, training courses from the CITI system should appear. If the courses are not appearing, Click the "?" on the top of this question to find out how to sync your accounts.

Name: Sarah Pitts
Organization: PWL REGISTRAR
Address:
Phone:
Email: pittss@purdue.edu

If you cannot find the name of the Purdue University personnel that you are looking for using the "Find People" button above, please list them here. We will need to verify their information and load into the system.

(First Name: Last Name: Purdue e-mail address)

If you wish to provide a campus phone number for the Primary Contact, you may list it here.

This field is optional. Most correspondences from the IRB will arrive via the Cayuse system.

*required
Key Personnel

Below is a definition of Key Personnel. Please read the definition and decide who will need to be listed as Key Personnel on the study. The PI defines the roles of each staff member based on the definition below.

Key personnel: The Principal Investigator and any project staff, students, postdoctoral staff, internal or external to Purdue University who contribute in a substantive way to the scientific development or execution of a project (including, but not limited to, consent, data collection or analysis).

Initial Submission

Study Personnel

*required
Study Personnel

In this section you will name all staff who will participate in the study.

*required
A Principal Investigator (PI) is responsible for all aspects of a research study. *STUDENTS ARE NOT AUTHORIZED TO BE PRINCIPAL INVESTIGATORS*

Provide the name of the Principal Investigator of this study.
All faculty (tenured, tenure-track, research and clinical) are eligible to be Principal Investigators. Others requesting to submit proposals as the Principal Investigator for the first time must obtain special approval.

Once the name is selected, training courses from the CITI system should appear. If the courses are not appearing. Click the "?" on the top of this question to find out how to sync your accounts.
Name: CORDELIA RUNNING
Organization: PWL NUTRITION SCIENCE
Address: 700 W. State Street , West Lafayette, IN 47907-0000
Phone:
Email: crunning@purdue.edu

If you cannot find the name of the Purdue University personnel that you are looking for using the "Find People" button above, please list them here. We will need to verify their information and load into the system.

(First Name: Last Name: Purdue e-mail address)

*required
Primary Contact

Provide the name of the Primary Contact of this study. The Primary Contact will be copied on all correspondence regarding the IRB review. Note that the Primary Contact

*required
Does your study have additional Key Personnel besides the PI and Point of Contact?

Once the name is selected, training courses from the CITI system should appear. If the courses are not appearing. Click the "?" on the top of this question to find out how to sync your accounts.

Yes

✓ No, the only personnel on the project are the PI and Point of Contact.

*required
Provide a brief description of each person's position at Purdue (e.g. student, staff, faculty) and their role in the study.

Examples:
Prof. Principal (faculty) will oversee all aspects of the study design and conduct
John Researcher (graduate student) will recruit and consent participants and collect data
Purdue Pete (staff) will analyze collected study data.
Dr. Running (faculty) will oversee the project design and protocol submissions.
Sarah Pitts (graduate student) will recruit participant, collect data, and write up reports.
Note: We originally had Dr. Lisa Mauer (faculty) listed on the work. She will NOT participate in any way until her the CITI training is complete and we add her back to the protocol. For now, Dr. Running and Ms. Pitts hope to continue the submission at very least, partially so that we can get feedback from the IRB about this proposed remote study, and whether it is still "exempt" in today's environment. We would be happy to revise as an expedited review instead if the IRB deems that nothing is truly exempt because nothing is truly minimal risk these days.

1. *Research on regular and special education instructional strategies*
2. *Research on the effectiveness of, or the comparison, among instructional techniques, curricula, or classroom management methods*

Category 2 Research that ONLY includes interactions through:

- *Surveys with adults*
- *Interviews with adults*
- *Focus Groups with adults*
- *Educational Tests (cognitive, diagnostic, aptitude, achievement)*
- *Observation of public behavior*

Category 3 Benign Behavioral Interventions.

Interventions that are brief in duration, harmless, painless, not physically invasive, not likely to have a significant adverse lasting impact on the subjects, and the investigator has no reason to think the subjects will find the interventions offensive or embarrassing.

Examples of Benign Behavior Interventions can include having participants:

- play an online game.
- solve puzzles under various noise conditions
- decide how to allocate a nominal amount of received cash between themselves and someone else

Category 4 Secondary analysis of samples or data.

NOTE: Before you will be able to submit this protocol, you will need to know the terms and conditions associated with receiving the existing data or specimens. You might also need to know the original intended use from the study's consent form. Contact the provider of the data or specimens to obtain this information before proceeding. You may also contact the Purdue IRB (irb@purdue.edu) for guidance.

Category 6 Food and Taste Acceptance

✓ *The research is only a taste and food acceptance quality evaluation or food consumer acceptance study*

Getting started with your submission

*required

Welcome to the submission system for the Purdue HRPP/IRB. Before you begin, you should be familiar with the framework of human research protections and how they relate to your proposed study. The materials to help you appear on our website.

Be certain that all personnel have completed online training prior to submitting the protocol.

Helpful Tip: Use the Create PDF button at the top of the page if you need to share a PDF version of this protocol for discussion with a reviewer outside of the Cayuse system.

The choices you make on the first two sections will help populate the required sections for your submission. Please look through the options and make the choice closest to your research. You can always seek assistance by scheduling an appointment with the HRPP Office or reviewing the materials at www.irb.purdue.edu.

Exempt study

Please look at the list of studies below. Determine if your proposed study design might fit into one of these descriptions.

Exempt research still requires review by the Human Research Protection Program. Choose this option if you believe your study is:

✓
- Research in a common educational setting (e.g. school, daycare) about normal educational practices.
- Educational Test, Survey, Interview, or Observation of Public Behavior
- A benign intervention involving short puzzles, games and their outcomes on human behavior conducted during a single day.
- Secondary Analysis of data, documents, records, pathological or diagnostic specimens that are publicly available or properly deidentified.
- Taste and Food Quality Evaluation or Consumer Acceptance Studies.

*required

Please choose a category. The proper sections will populate based on your selection.

Category 1 Research conducted in established educational settings with normal education practices like:

Research Sites

*required

Where will the study take place?

Purdue University

✓ External Site (non Purdue University)

*required

Please list the external sites. Keep in mind that later in the application process, you will be asked for appropriate permission letters to document the site's agreement to allow your team to conduct research.

Samples will be delivered in one of three ways: Delivery to home, pick up from Stone Hall CRC, or pick up from a local grocery store parking lot. Video meetings and email will be utilized to communicate with participants and guide them through the tasting and rating process of the foods we test. In the attachments you can find the SOP for the location where the cookies will be made and packaged and the SOP for picking up through the CRC room 144. A remote study protocol was also created and can be found in the other attachments section. Once packaged, the packages will be left for at least 24 hours before delivery or pickup. Pick ups will be scheduled so only one participant would be picking up a package at a time. This scheduling will be done through the RedJade software. If picking up is deemed unsafe we will revert to delivering or mailing all packages to individual's homes where there will be no face-to-face contact.

*required

Are any of the sites outside of the United States?

The IRB may need to make special considerations when reviewing international research.

Yes

✓ No

Non-exempt study

Research that does not fit into an exempt category typically involves the collection of new data from a participant.

Just-in-time

I have been contacted by a sponsor (often NSF or NIFA/USDA) to provide documentation of IRB approval, (such as Just-in-Time or JIT) but my application to the IRB is dependent on other factors such as:

- *completion of instruments*
- *prior animal studies*
- *purification of compounds*

Note: This category should be utilized ONLY if the above criteria apply. If study procedures are discernible at the time of the sponsor request, please do not select this option. The research team should affirm that their sponsor will accept documentation for a development protocol.

If you request this study type, the title of the IRB protocol must exactly match the title of the grant proposal. Most funding agencies will not accept protocols with different titles.

Quality Improvement

My research involves activities without a plan to conduct research (Case Report or Quality Improvement project)

I need to know if my project is considered "Human Subjects Research"

I would like to request that another IRB Review this study. (Request for Purdue IRB to defer to another site).

When Purdue University will be engaged in human subject research with one or more institutions, investigators may submit a Request for Deferral asking that the review be deferred to one institution's Institutional Review Board (IRB).

Category Six Exemption Taste and Food Quality Evaluation/ConsumerAcceptance Studies

*required

Is the research ONLY a taste and food acceptance quality evaluation or food consumer acceptance study?

Select no if the study will collect specimens, or involve questions outside of taste/food quality or consumer acceptance.

✓ Yes

No

*required

Does your study involve children?

Yes

✓ No

*required

Will your taste/food quality or consumer acceptance study utilize only wholesome food without additives?

To judge if a food is wholesome, consider food intended for human consumption that meets all quality and labeling standards imposed by Federal, state and local laws and regulations.

✓ Yes

No

*required

Do you agree to inform participants in your food quality or consumer acceptance study that their participation is voluntary?

✓ Yes

No

*required

Please attach or enter text that describes the language the study team will use to inform participants that participation is voluntary.

During recruitment as well as at the beginning of each tasting/training session, all participants will indicate digitally that they understand the study is voluntary. The software we use to ask the questions about foods automatically includes this confirmation at the beginning of each testing session.

At the beginning of each test, the following will be displayed on screen. Participants can only proceed to the test if they click "I agree" after reading the text (they have to actually scroll to the bottom).

Welcome

Today's test:
We are teaching people how to describe and rate the texture and sweetness of baked goods. We will then use those people's new skill in taste testing to taste and characterize the texture and sweetness of a variety of cookies that have their sugar replaced with various dietary fibers.

Time: ~30 minutes

Food ingredients: *(insert list of today's ingredients)*
If you are allergic to any of these ingredients, click "I disagree," as it is not safe for you to participate in this test! Then please dispose of your samples.

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

If you have questions, comments or concerns about this research project, you can talk to one of the researchers.
Please contact Dr. Cordelia Running, 765-494-2282.
If you have questions about your rights while taking part in the study or have concerns about the treatment

*required

Please list the wholesome food(s) being tested for taste/food quality or consumer acceptance.

The wholesome foods will include: Cookies, bread, crackers, baked goods, and candy. Some will be purchased from local grocers and some will be made in our kitchen. A full list of ingredients will be included for viewing by the participant.

*required

Do you agree to inform participants that any food, especially those that are highly allergenic (such as peanuts or milk) could present the risk of an allergic reaction?

✓ Yes

No

*required

Please attach or enter text that describes the language the study team will use to inform participants about allergy or risk of consumption.

Participants will be recruited using the SPIT lab (Dr. Running's lab) participant pool. These individuals have agreed to be contacted about potential research studies involving foods and food ingredients. Interested individuals will be asked if they have any food allergies, and excluded if they do. Even if they do not say they have food allergies, we will provide a full list of all ingredients used in the food items to the participant before they consume any food. Before consuming and rating foods for flavor attributes, participants will be reminded of the ingredient list, and asked to acknowledge they are willing and able (not allergic!) to consume these ingredients.

You may attach scripts or fliers here as appropriate.

of research participants, please call the Human Research Protection Program at (765) 494-5942, email (hboard@purdue.edu)or write to:
Human Research Protection Program - Purdue University
Ernest C. Young Hall, Room 1032
155 S. Grant St.,
West Lafayette, IN 47907-2114

By clicking the "I agree" button, I am providing my consent to participate in this research.

You may attach scripts or fliers here as appropriate.

*required

Will subjects receive payment or other incentives for their participation in the study?

✓ Yes

No

*required

Describe the payment or incentive

Estimate the maximum total payment. Please indicate what information you will be collecting from subjects who will be paid for their participation.
We will give participants small gift cards (<=$25) for coffee or local restaurants if they participate in the study. Participants who do not complete all the sessions will receive $10, and those who do complete all sessions will receive $25 cards.

Sorry, there is no place in the exempt form to indicate that multiple taste-test sessions are involved. Participants may still quit at any time, but total we anticipate 10-15 training sessions on the taste and texture of the baked goods, and 5-10 tasting sessions for the cookies we make with the fiber replacing some of the sugar. Again, we will never have face-to-face contact with subjects. All tasting items will be dropped off at front doors, and we will email participants to let them know the package was delivered. Any additional contact would be through WebEx.

Exempt-Your research appears to be eligible for exemption under Category 6. You will be guided to answer just a few more items before submitting your protocol.

This exemption determination is subject to review by the HRPP Office. Please do not begin your research until you receive the final determination letter. All personnel listed in the application must complete training prior to conducting research.

Please click continue to move on to the next required sections.

Funding Source(s)

*required

CURRENT Funding Source(s)

To review your protocol appropriately with differing sponsor standards, the HRPP must have the accurate funding source. It is a PI's responsibility to update funding sources as a modification to the protocol and associated forms when funding changes.

Please list any sources of funding that are **confirmed** by contract, agreement, or other support of a sponsor.
You will list any pending sources in the next question.

- Externally sponsored (federal, state, corporate, foundations, industry, donor)
- ✓ Internal Purdue University Funds (Includes departmental funds, start-up funds.) *(Note, this does not include Purdue Research Foundation or Purdue Research Park companies-please list as external sponsor above).*
- None - There are no confirmed funding sources at this time.

*required

ANTICIPATED Funding Source(s) - Required

To review your protocol appropriately with differing sponsor standards, the HRPP must have the accurate funding source. It is a PI responsibility to update funding sources as a modification to the protocol and associated forms when funding changes.

If you are a student or staff member filling this out on behalf of a Principal Investigator (PI), please be certain to affirm with the PI that this information is accurate.

Please list any sources of funding where sponsorship is **anticipated** or pending a final decision.

- ✓ Externally sponsored (federal, state, corporate, foundations, industry, donor)

Please enter the full sponsor name(s) in the text box below.

Conflict of Interest and/or Outside Activities Disclosure

Conflicts of interest or outside activities must be disclosed and managed prior to IRB approval. For more information about these policies, please consult the resources listed in the question marks in each section.

The IRB may request confirmation of proper disclosures.

*required

Does this IRB protocol involve any work, advice, or service for an entity other than Purdue University?

For example, if this activity is done as an outside consulting activity, or employee's start-up company, this activity will not qualify for review by the Purdue IRB and an outside IRB or service must be sought.

- ✓ I attest that I understand the outside activities policy and Individual Financial Conflict of Interest policies and that all members of the research team are conducting this project on behalf of Purdue University.

*required

Do you or any investigator(s) participating in this study have a significant financial interest (SFI) related to this research project?

Receiving more than $5,000 in compensation from, or having ownership interests in, outside entities, constitute Significant Financial Interests that need to be disclosed. Definitions of SFI, Investigator and Institutional Responsibilities, can be found at https://www.purdue.edu/policies/ethics/iiib2.html#definitions.

- Yes
- ✓ No

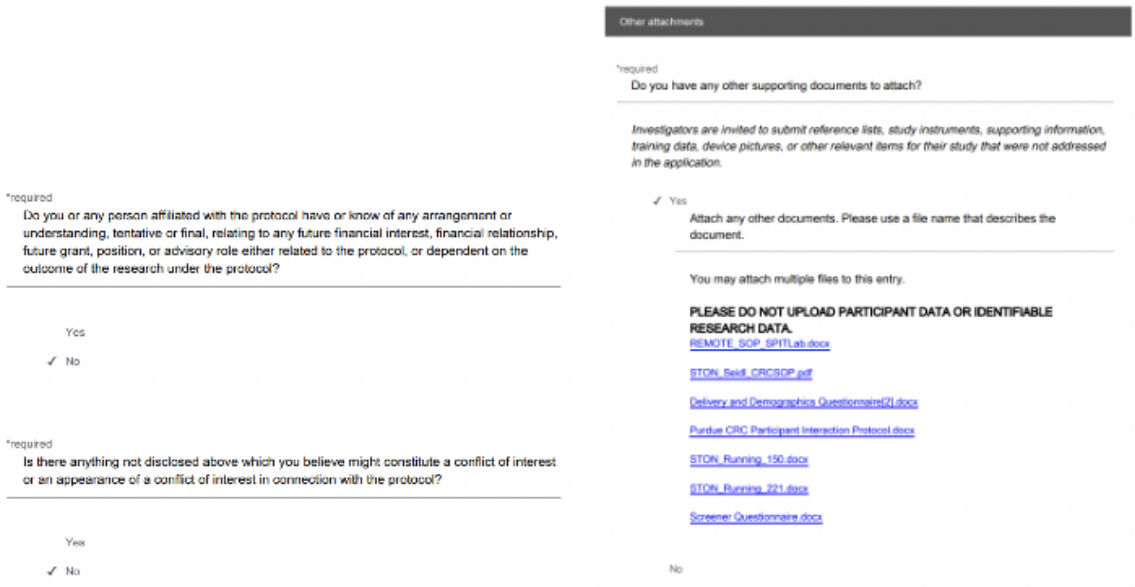


Figure A-1 Institutional Review Board (IRB) approved submission for descriptive analysis panel to analyze the texture perception of wire-cut cookies formulated with sucrose and sucrose replacers.

Screener Questionnaire

The following questionnaire will be sent to potential participants from the SPIT lab participant pool via email. Individuals can choose to take this questionnaire if they are interested in participating in the remote descriptive analysis panel. This questionnaire will ask participants about their teeth, age, dietary restrictions, and food allergens.

Thank you for your interest in our study.

By taking this survey you will be considered for participation in a study that will take place over a several week period. If you qualify you will receive an email with additional information about the study. If you wish to continue, please use the link below to complete the pre-screening questionnaire.

{Qualtrics link}

By taking the questionnaire, you consent to being asked about topics including your age, dietary restrictions, oral hygiene habits, and proximity to the Purdue – West Lafayette Campus. Our research lab will not share this information with anyone else. If you decide not to complete the full questionnaire, we will delete your information. You may either contact us at purduespit@gmail.com to request we delete your information, or we will automatically delete the data from incomplete surveys at the end of the study recruitment period.

The following block of text will function as a screening questionnaire. This survey will be used to find qualified participants. If they do not wish to continue with the survey, they may select "no", and the survey will end. If they select "Yes", they will be directed through the questions below.

Thank you for participating.
By selecting "Yes", you consent to being asked about the delivery options and demographic questions. Our research lab will not share this information with anyone else. If you decide not to complete the full screening process, we will delete your information. You may either contact us at purduespit@gmail.com to request we delete your information, or we will automatically delete the data from incomplete screening surveys at the end of the study recruitment period.

*Would you like to continue? If so, please select **"Yes"**.*

*If you would not like to continue, please select **"No"** and the survey will end.*

1. *What is an email we can contact you at?*

   _____

2. *Please enter your year of birth.*
   _____ *(ex. XXXX)*

3. *Do you regularly visit the orthodontist?*
   Yes *or* ***No***

   If yes, do you have braces or permanent retainers?
   Yes *or* ***No***

4. *Do you have a full set of teeth?*
   Yes *or* ***No***

5. *Do you live within 20 minutes driving distance from the Purdue – West Lafayette Campus?*
   Yes *or* ***No***

6. *Will you remain in the West Lafayette from through May 15th of 2021?*

   Yes, No, *or* ***Unsure***

7. *Do you have any food allergies or dietary restrictions?*

   Yes *or* ***No***

   If yes, please list allergens or restrictions below.

   _____

Figure A-2 Screener questionnaire sent to potential panelists to determine eligibility for the descriptive analysis panel.

Delivery and Demographic Questionnaire

The following block of text will be emailed to qualified participants and provide the link for them to complete the delivery and demographic questionnaire. The questionnaire will ask participants about their height, weight, oral hygiene habits, and availability for delivery of the tasting kit.

Thank you for your interest in our study.
If you do not wish to continue participating in our study, please ignore this email. If you wish to continue, please use the link below to complete the delivery and demographic questionnaire.
https://purdue.ca1.qualtrics.com/jfe/form/SV_6FsD4JYT4ERLh1r
By taking the questionnaire, you consent to being asked about topics including your height, weight, oral hygiene habits, and availability for delivery of the tasting kit.
Our research lab will not share this information with anyone else. If you decide not to complete the full questionnaire, we will delete your information. You may either contact us at purduespit@gmail.com to request we delete your information, or we will automatically delete the data from incomplete surveys at the end of the study recruitment period.

The following block of text will function as delivery and demographic questionnaire. It will be on the first screen that qualified participants see when they click the link to take the survey. If they do not wish to continue with the survey, they may select "no", and the survey will end. If they select "Yes", they will be directed through the questions below.

Thank you for participating in our study.
By selecting "Yes", you consent to being asked about the delivery options and demographic questions. Our research lab will not share this information with anyone else. If you decide not to complete the full screening process, we will delete your information. You may either contact us at purduespit@gmail.com to request we delete your information, or we will automatically delete the data from incomplete screening surveys at the end of the study recruitment period.

*Would you like to continue? If so, please select **"Yes"**.*

*If you would not like to continue, please select **"No"** and the survey will end.*

Delivery Options:

The following block of text will function as delivery questionnaire. It will be included in the questionnaire for qualified participants to choose their prefer delivery options when they click the link to take the survey.

The following survey will ask you about your preference for delivering the sample kit.
Kits will be delivered by dedicated study personnel who will take the kits directly from storage to the pick-up location that you selected, with no intermediate stops. Select the delivery option that works for you:

- ***Pick up at local grocery store parking lot in the Lafayette/West Lafayette area***

  We will schedule times when we can meet you at a local grocery store parking lot and place the kit in your car (similar to grocery "contactless pick up").

- ***Pick up on campus, Stone Hall***

  Study personnel will not physically interact with participants. Kits will be placed on the pick-up spot outside Sone Hall during the prearranged time, and participants will be emailed that the kit has been placed. If participants are present when study personnel reaches the pick-up spot, then the kit will be placed on the ground at least 6 feet from the participant so that the individual can retrieve it after study personnel has retreated.

If the participant selects neither of the above options, the option below will populate.

- ***Deliver to your home if you live in the Lafayette/West Lafayette area (NOTE: this option requires you to give us your address)***

  Study personnel will not physically interact with participants. Kits will be left at/near the front door of the home, and participants will be emailed that the kit has been delivered. If participants are present when study personnel reach the home for the delivery, then the kit will be placed on the ground at least 6 feet from the participant so that the individual can retrieve it after study personnel have retreated.

  - *If you prefer we deliver the sample kit to your home, please provide your address below. ("NOTE: Your address information will be destroyed upon completion of the delivery.")*
    Address Line 1: _____
    Address Line 2: _____
    City: _____ (Lafayette or West Lafayette)
    State/Province: IN
    Zip/Postal Code: _____
    Country: United State (US)

Demographic questionnaire:

The following block of text will function as additional demographic questionnaire. It will be included in the questionnaire for qualified participants followed by the above delivery options.

The following survey will ask you demographic questions and questions about your general diet as well as some questions related to the study.

1. *Which gender do you most identify with?*

Male, *Female*, or *Other*

2. *What is your biological sex?*

Male, *Female*, or *Other*

3. *Please enter your year of birth*

_____

4. *What is your age?* _____ *(enter number)*

5. *Please select your racial background (you can check more than one).*

Caucasian, or White

African, African American, or Black

Asian, Southeast Asian, or Indian

Native Hawaiian or other Pacific Islander

Native American or Native Alaskan

Hispanic or Latina/o

Other

Prefer not to answer

6. *What is your height?*

_____ *(feet)* _____ *(inch)*

Or

_____ *(cm)*

7. *What is your weight?*

_____ *(lb)*

Or

_____ *(kg)*

Figure B-3Questionnaire for descriptive analysis panel distributed via Qualtrics to determine panelist availability for sample pick up.

Please ensure you have the following samples:

942, 726, 536, 280, 647, 394, 347, 525

This study involves tasting samples that contain:

Sugar, enriched flour (bleached wheat flour, malted barely flour, niacin, ferrous sulfate, thiamine mononitrate, riboflavin, folic acid), water, soybean oil, brown sugar, corn syrup, butter, modified corn starch, glycerin, egg, cinnamon, tallow, palm oil, salt, defatted soy flour, egg white, baking soda, sodium acid pyrophosphate, whey, potassium sorbate, hydrogenated tallow, mono and diglycerides, polysorbate, monocalcium phosphate, sodium stearoyl, lactylate, fumaric acid, calcium caseinate, sodium caseinate, soy protein isolate, cottonseed oil, soy lecithin, beta carotene, and vitamin A Palmitate, raisins, molasses, ginger, canola oil, high fructose corn syrup, semi-sweet chocolate chips, rice flour, cane sugar, natural vanilla flavor, xanthan gum, ammonium bicarbonate, cream of tartar, nonfat milk, dextrose, gelatin, tetrasodium pyrophosphate, and blue 1.

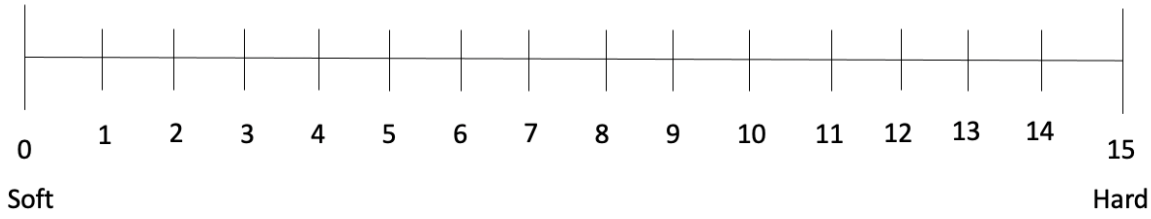
If you have an allergy to any of the ingredients listed, you should stop immediately and not taste any samples.

Please note these products would have been handled in our lab, where other ingredients including common allergens are present.
Because other ingredients are handled in our lab, we recommend you do not participate in the study if you have any severe food allergy, even if it is not listed above.

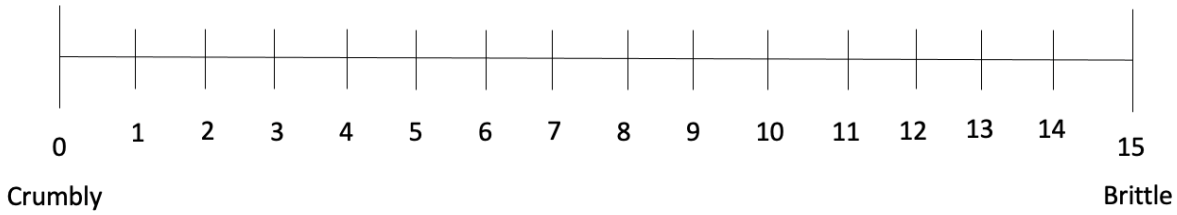
Hardness:
Fracturability:
Cohesiveness:
Sweetness:
Pastiness:
Crumbliness:

Sample: 212

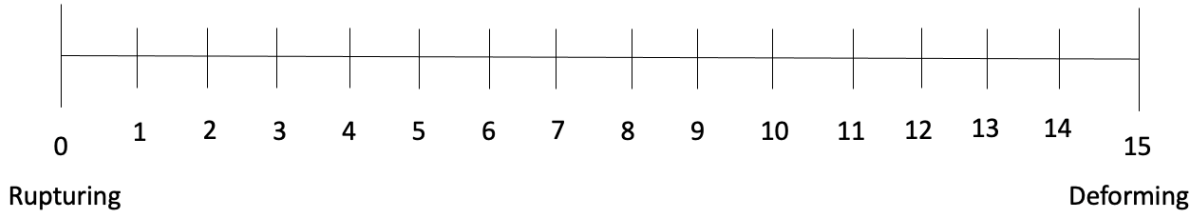
Hardness: The force to attain a given deformation



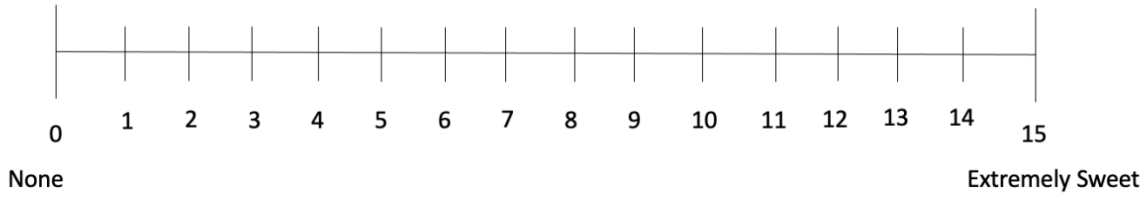
Fracturability: The force with which the sample breaks



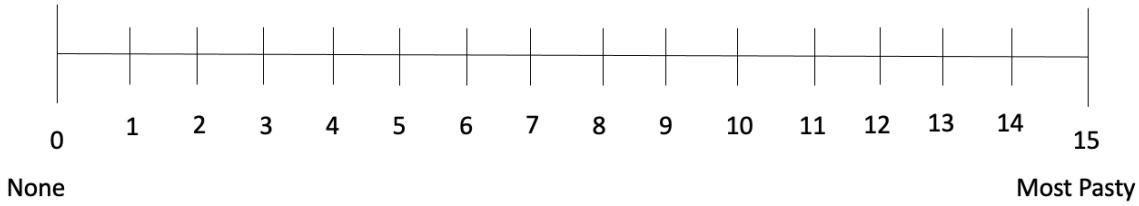
Cohesiveness: The degree to which sample deforms rather than crumbles/breaks/cracks



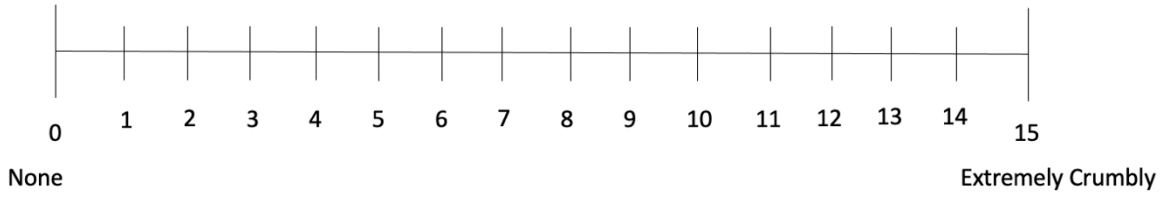
Sweetness:



Pastiness: The degree to which cookie forms a paste in the mouth

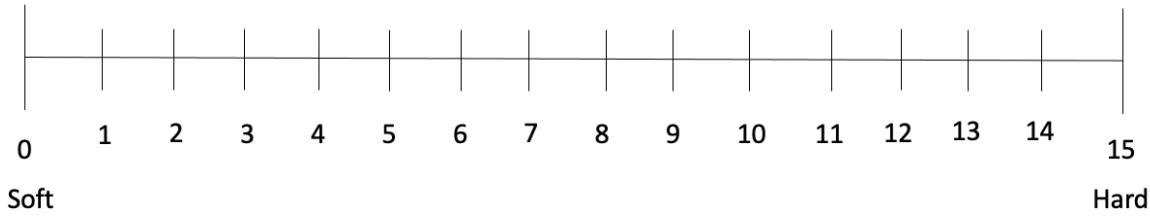


Crumbliness: The degree to which a sample breaks apart in the mouth

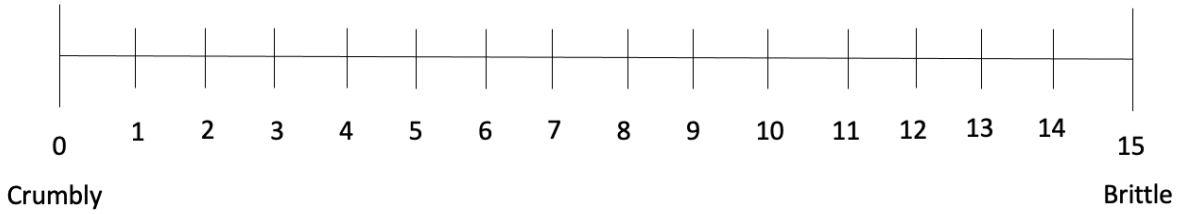


Sample: 319

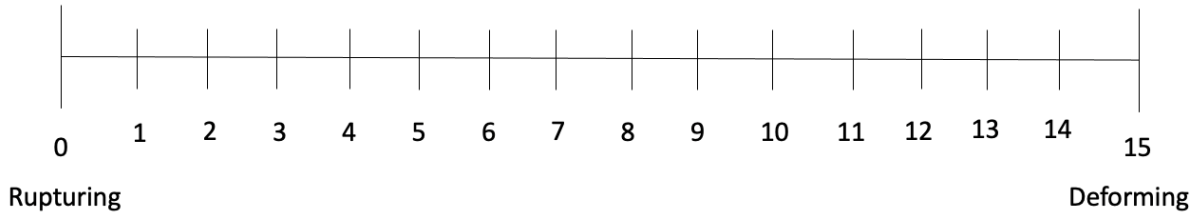
Hardness: The force to attain a given deformation



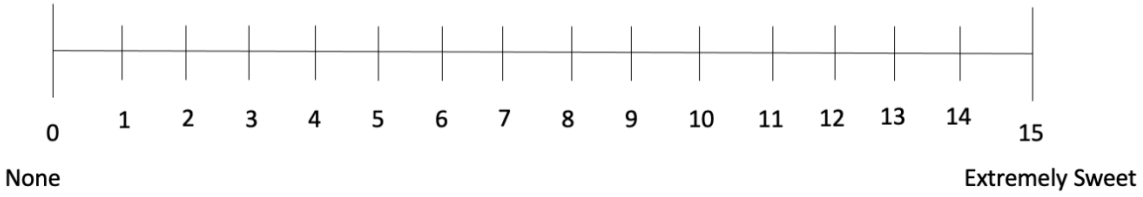
Fracturability: The force with which the sample breaks



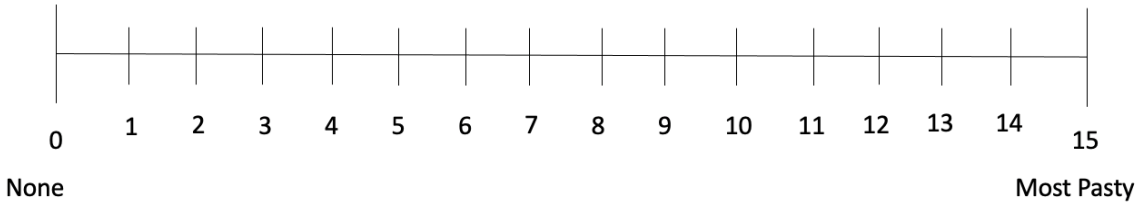
Cohesiveness: The degree to which sample deforms rather than crumbles/breaks/cracks



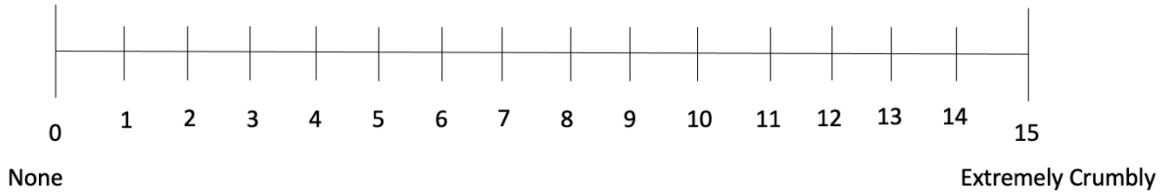
Sweetness:



Pastiness: The degree to which cookie forms a paste in the mouth

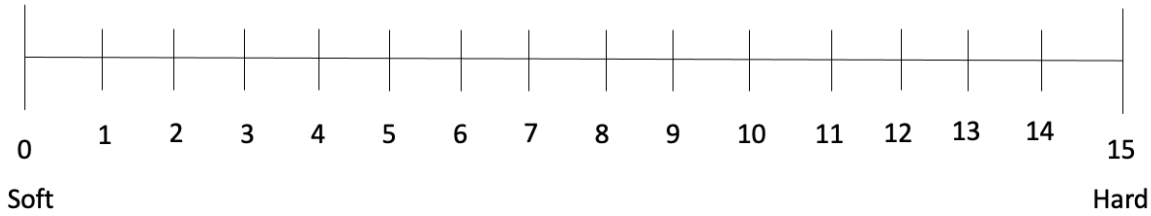


Crumbliness: The degree to which a sample breaks apart in the mouth

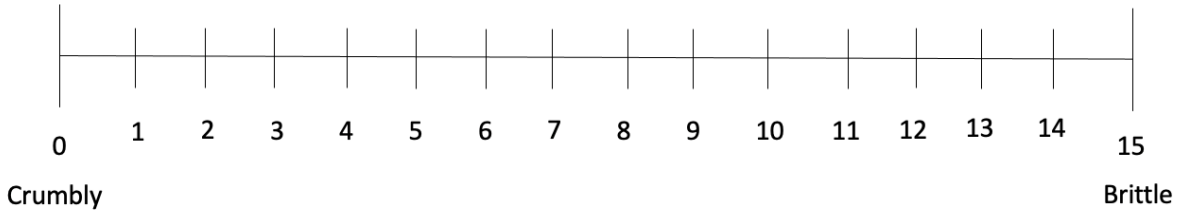


Sample: 405

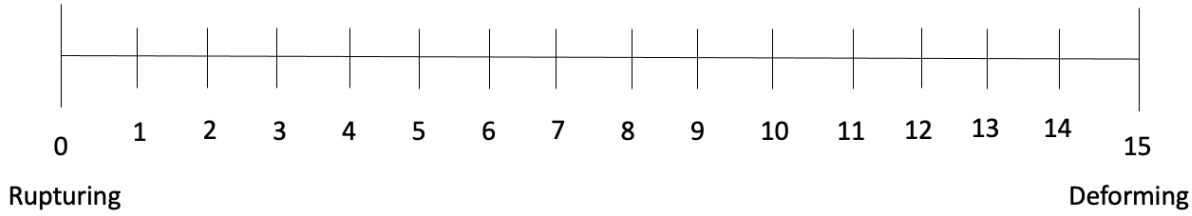
Hardness: The force to attain a given deformation



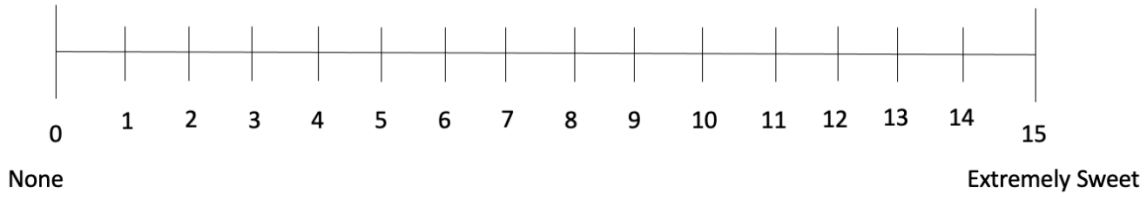
Fracturability: The force with which the sample breaks



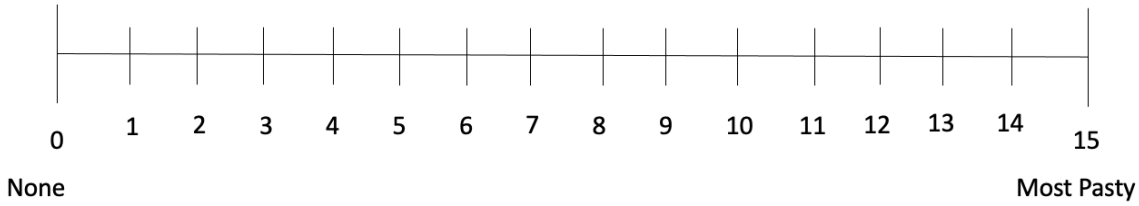
Cohesiveness: The degree to which sample deforms rather than crumbles/breaks/cracks



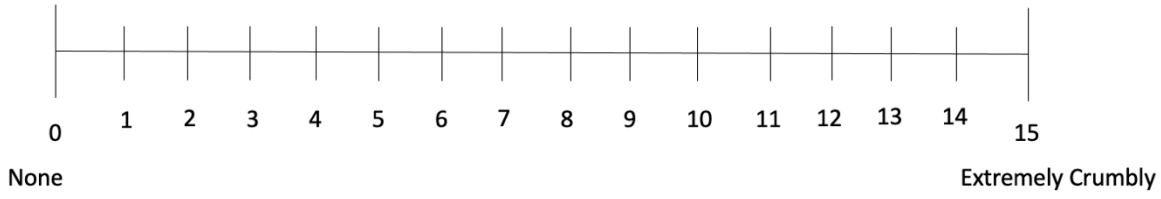
Sweetness:



Pastiness: The degree to which cookie forms a paste in the mouth

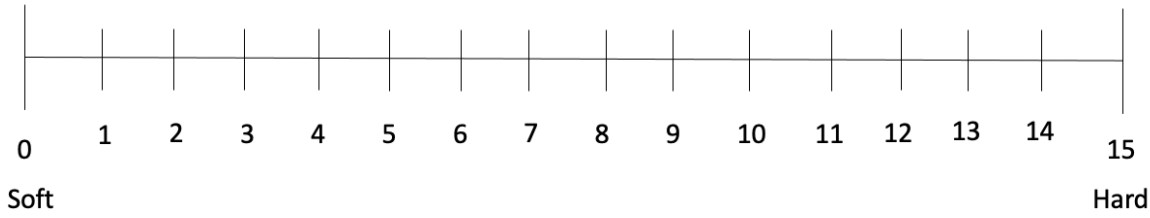


Crumbliness: The degree to which a sample breaks apart in the mouth

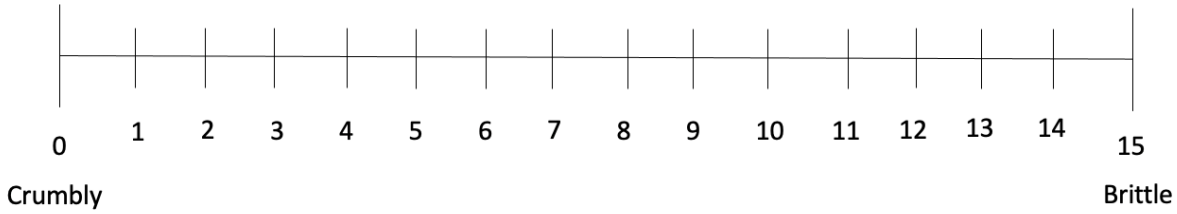


Sample: 862

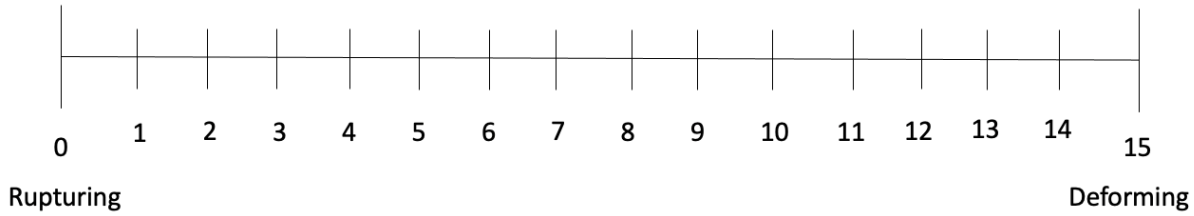
Hardness: The force to attain a given deformation



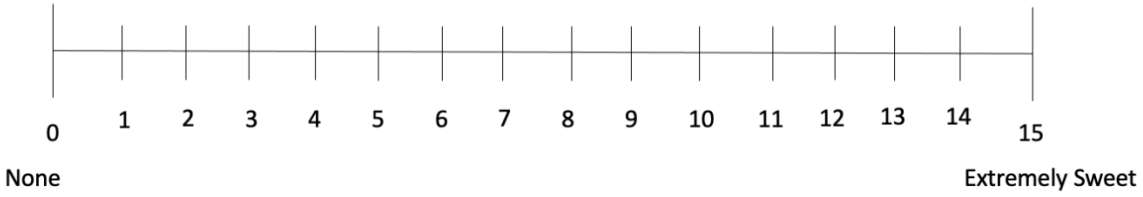
Fracturability: The force with which the sample breaks



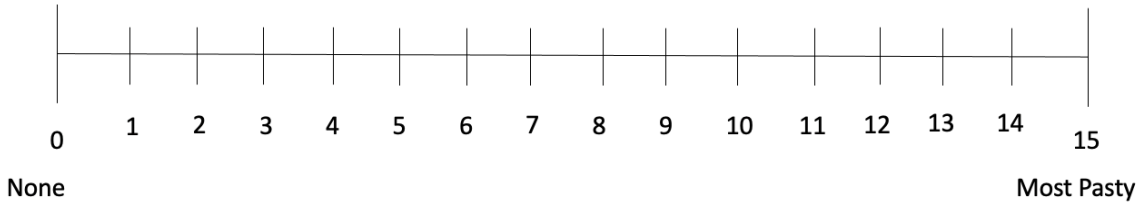
Cohesiveness: The degree to which sample deforms rather than crumbles/breaks/cracks



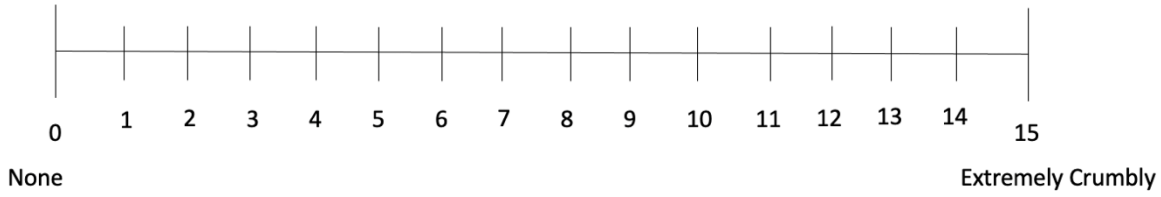
Sweetness:



Pastiness: The degree to which cookie forms a paste in the mouth

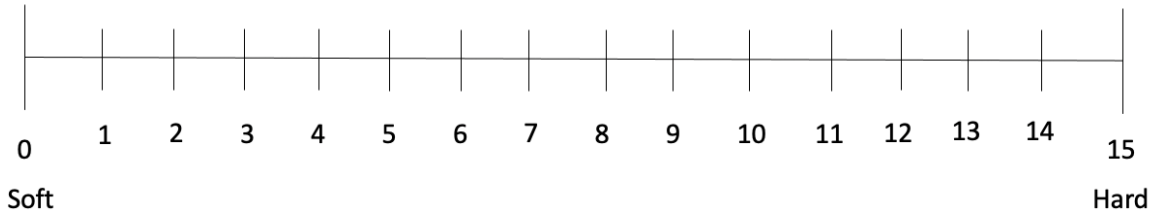


Crumbliness: The degree to which a sample breaks apart in the mouth

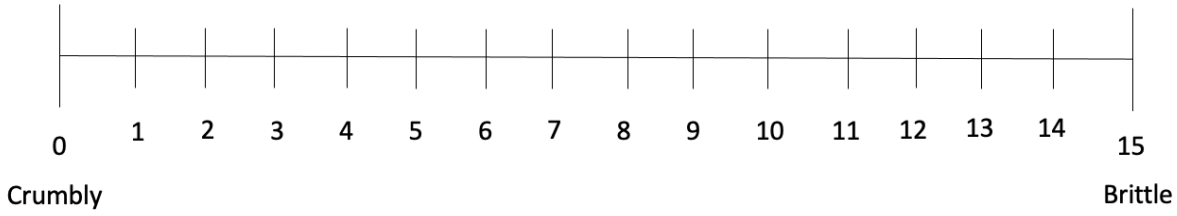


Sample: 499

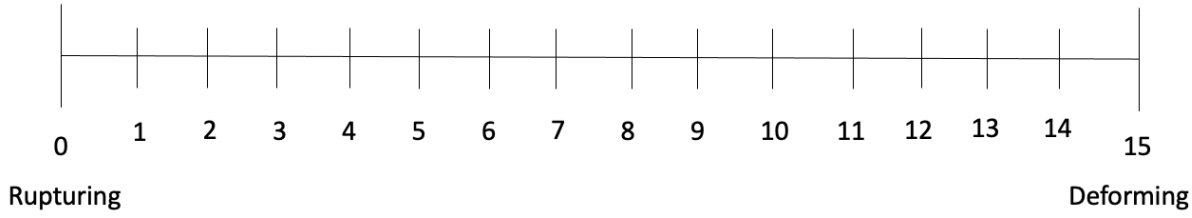
Hardness: The force to attain a given deformation



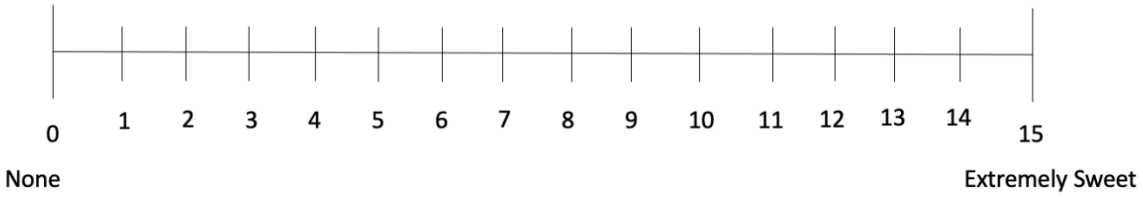
Fracturability: The force with which the sample breaks



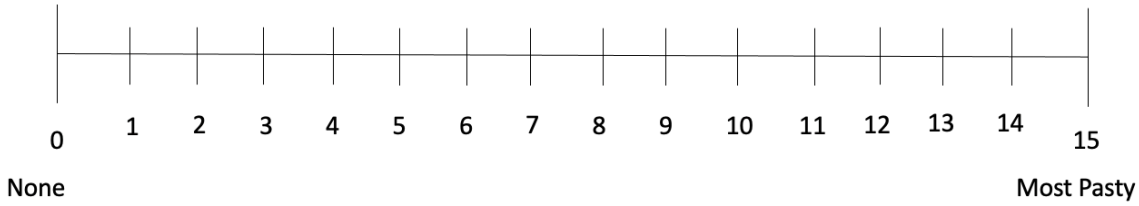
Cohesiveness: The degree to which sample deforms rather than crumbles/breaks/cracks



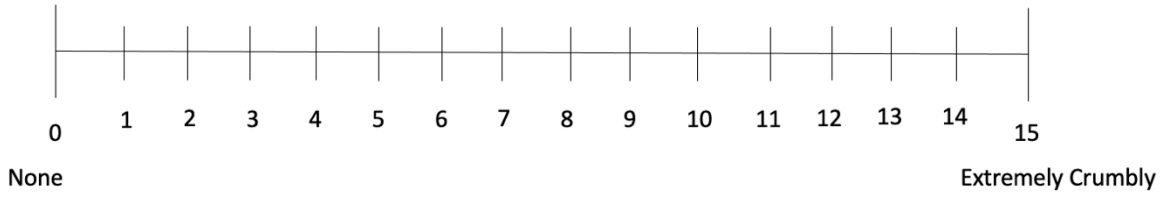
Sweetness:



Pastiness: The degree to which cookie forms a paste in the mouth

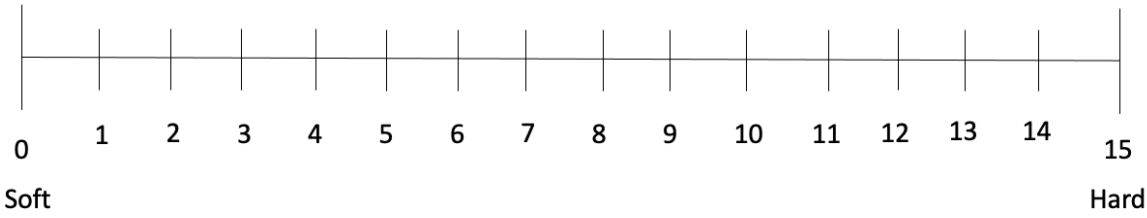


Crumbliness: The degree to which a sample breaks apart in the mouth

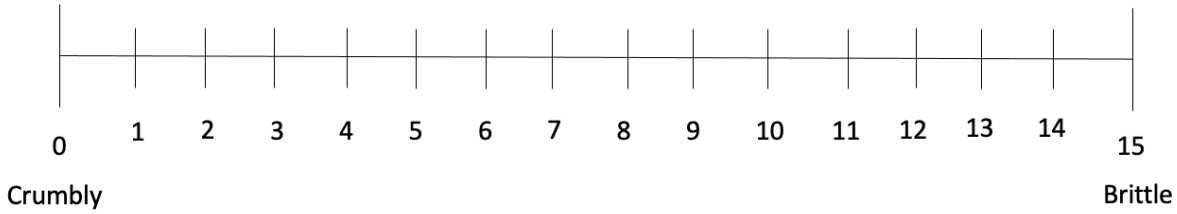


Sample: 659

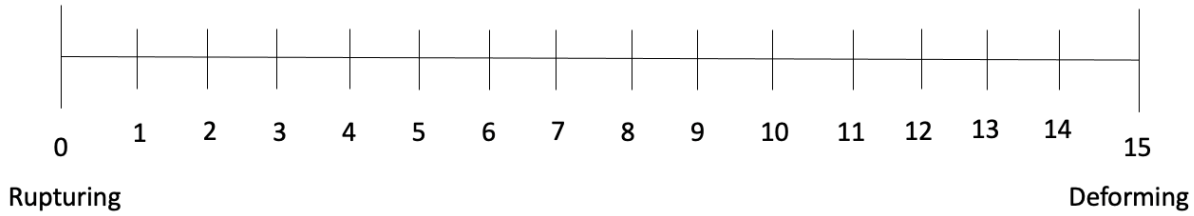
Hardness: The force to attain a given deformation



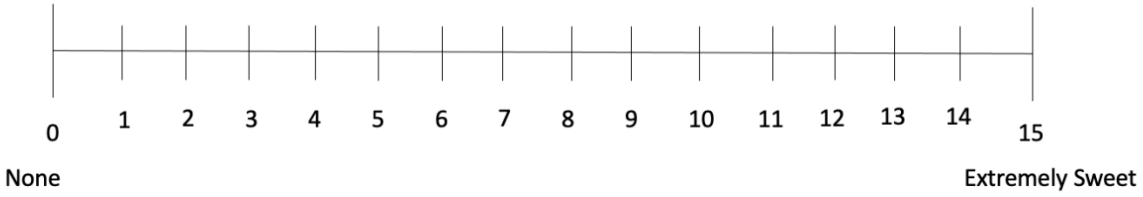
Fracturability: The force with which the sample breaks



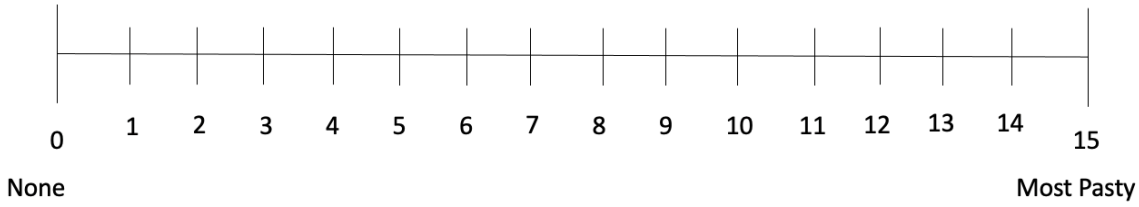
Cohesiveness: The degree to which sample deforms rather than crumbles/breaks/cracks



Sweetness:



Pastiness: The degree to which cookie forms a paste in the mouth



Crumbliness: The degree to which a sample breaks apart in the mouth

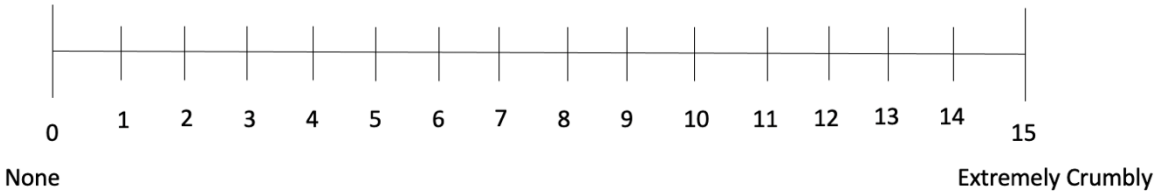


Figure A-4 Intensity score rating handout provided to panelists with samples.

```
In [ ]: import pandas as pd
        import numpy as np
        import saspy as sas
        import saspy.sascfg
        sas = saspy.SASsession(cfgname='default', results='pandas')
        #import seaborn as sns
        #from scipy import stats

In [ ]: cookies = pd.read_csv('./DAPanelCookiesRawData20210629.csv')

In [ ]: cookies.head(2)

In [ ]: cookies['Un1'] = cookies.ID.astype(str).str.cat(cookies['Test'].astype(str), sep="_")
        cookies['Un2'] = cookies.Un1.astype(str).str.cat(cookies['Sample'].astype(str), sep="_")
        cookies.info()

In [ ]: cookies.head(2)

In [ ]: cookiesub = cookies.drop(columns={"Hardness","Fracture","Cohesive","Sweetness","Pastiness","Crumbliness","Un1"} )
        cookiesub = cookiesub.drop_duplicates()

In [ ]: cookiesub.head(2)

In [ ]: cookstack = pd.melt(cookies, id_vars="Un2",
                           value_vars=( 'Hardness', 'Fracture','Cohesive','Sweetness',
                                        'Pastiness', 'Crumbliness'),
                                       var_name="Quality", value_name="Rating")
        cookstack.head(2)

In [ ]: cooklong = cookstack.merge(cookiesub, on="Un2", how="left")
        cooklong.info()

In [ ]: cooklong.head(2)
```

```
In [ ]: cooksas = sas.df2sd(cooklong,'cooklong')

In [ ]: %%SAS sas

proc sort data = cooklong;
by Quality sample replicate test ID;
run;

title 'Cookies';
ods output diffs = diff tests3=tests lsmeans =means  lsmESTIMATEs =Estim FitStatistics=fit;
Proc mixed data=cooklong;
by quality;
class ID Quality SampleN test replicate;
model rating =  samplen / ddfm = kr;
*note - something weird with hardness. Test and replicate are signifcant only for that...;
repeated / subject = ID type = cs;  *residual goods;
lsmeans samplen/ pdiff ADJDFE=ROW adj=tukey;
run;

In [ ]: %%SAS sas

proc print data = tests;
proc print data =diff;
run;

In [ ]: diffsas = sas.sd2df('diff')
testssas = sas.sd2df('tests')
meanssas = sas.sd2df('means')

In [ ]: diffsas.to_csv('./LSMDifferences.csv')
testssas.to_csv('./Type3Tests.csv')
meanssas.to_csv('./LSMeans.csv')

In [ ]:
```

Figure A-5 Code utilized to analyze the descriptive analysis panel data in Python and SAS using Jupyter lab.

APPENDIX B. METHODS AND DATA COLLECTION FOR INVERT SUGAR PROJECT

The effects of glucose, fructose, sucrose, and invert sugar on the wheat starch gelatinization temperature (T_{gel}) were investigated. Starch T_{gel} and retrogradation were measured using differential scanning calorimetry. Pasting properties were analyzed using a Rapid-Visco analyzer (RVA) and a rheometer was used to investigated rheological properties. Data can be visualized below in a variety of tables and figures which are assembled for a future publication.

Materials and Methods

Materials

The native wheat starch used in this study was Aytex® P from ADM (Minneapolis, MN) with the following composition: 25% amylose, 9.9% moisture, <0.2% ash, <0.2% protein, and <0.1% fat. The sweeteners investigated were analytical grade glucose and fructose from Acros Organics (Fair Lawn, NJ) and sucrose from Mallinckrodt Chemicals (Phillipsburg, NJ). The sweeteners in this study were chosen to compare the effects of glucose and fructose by themselves, when combined in a 50:50 mixture (invert sugar), and when bound through a glycosidic linkage (sucrose) on wheat starch thermal properties responsible for the texture characteristics of low-moisture baked goods. The water (control) used in this study was ultrafiltered water from a Barnstead E-Pure Lab Water System (Dubuque, IA) to > 17.4 MΩ-cm.

Sweetener Solution Preparation

The sweetener solutions examined in this study were made on a % w/w dry basis and encompassed 0%, 15%, 30%, 45%, and 60% concentrations with the exception of glucose for which the highest concentration achieved was 45% due to solubility limits (≈ 50%). The sweetener solutions were prepared in 50 mL centrifuge tubes by first adding a predetermined amount of water (23 – 45 g) depending on voluminous nature of the sweetener, calculating sweetener dry weight necessary to achieve the desired final % w/w concentration, and then recording the actual weight of sweetener added to the solution. The sweetener-water mixtures were then agitated with an HT Mini vortexer (OPS Diagnostics, Lebanon, NJ) and a Roto-Shake Genie (Bohemia, NY) until

crystals were no longer evident after visual examination. The solutions with higher solids contents (45% and 60%) were briefly placed on a heating block (<5 min) heated to 80°C to aid sweetener dissolution during mixing. Once the sweeteners were cooled and mixed sufficiently they were either used immediately for wheat starch thermal property experiments or stored in the refrigerator (at 4°C).

Gelatinization Temperature

The gelatinization temperatures (T_{gel}) of wheat starch in the presence of sweetener solutions were measured with a DSC (Perkin Elmer) using an adapted method from Allan et al. (2018). The samples were prepared by combining wheat starch in a 1:2 (w/w) ratio with DI water or sweetener solution in a 1 mL centrifuge tube. Samples were vortexed to form slurries and allowed to rest overnight at room temperature (~23°C). The next day, samples were vortexed again before pipetting 15 to 20 mg into a DSC pan which was then hermetically sealed and placed into a the DSC cell along with an empty reference pan. Samples were heated from 10°C to 120°C at a rate of 10°C/min and the purge gas used was 20mL of N_2. Pyris software was used to calculate the onset temperature (T_{gel}), peak temperature, area under the curve, and enthalpy (ΔH) of each sample. An indium reference sample was used to calibrate the DSC.

Starch Retrogradation

The retrogradation behavior of starch in the presence of sweeteners was also measured using DSC. Samples (1:2 starch:solution ratio) were prepared in 1mL centrifuge tubes and stored overnight at room temperature (~ 23°C). The samples were then vortexed and 15 to 20 mg was pipetted into a DSC pan. The pan was hermetically sealed and placed in a Perkin Elmer DSC 4000 (Waltham, MA) along with an empty DSC pan for reference. Samples were heated from 30°C to 110-115°C at 10°C/min and then cooled to 30°C at 40°C/min to gelatinize the starch. Samples were then stored at 4°C for further analysis at day 0 and day 7. On days 0 and 7 samples were heated in the DSC from 30°C to 120°C at 10°C/min. Pyris software was used to calculate area under the curve, enthalpy (ΔH), onset temperature, and peak temperature. All analyses were done in triplicate and are reported as averages.

Pasting Properties

The effects of sweetener type and concentration on the pasting properties of wheat starch were determined using a Newport Scientific RVA-4 Rapid Visco Analyzer to measure its viscosity during pasting. Each sample contained 2.5 g of wheat starch and 25.5 g of solution, which were combined directly in a metal RVA canister and mixed with a plastic RVA paddle until the slurry appeared homogeneous. This was done within two minutes of the start of each run, to maintain equal contact time between the starch and sugars before the pasting process. The RVA was zeroed every day before running samples, with the paddle attached that would be used for mixing the slurries. All of the RVA runs were set to the "standard 1" method, which involved a paddle mixing speed of 960 rpm for the first 10 sec and 160 rpm for the rest of the 13 min run. The temperature was held at around 50°C for the first minute and then began to increase until it reached 95°C at 4 min 42 sec where it was held until 7 min 12 sec. After that, the temperature began to decrease until it returned to 50°C at 11 min, and the RVA maintained that 50°C temperature for the remaining 2 min. After the RVA run finished, the contents of the first sample of each solution were divided into four amounts for analysis by the rheometer. The same was done to the second RVA sample, but they were stored for rheometer analysis seven days later.

Rheological Properties

Two of each set of triplicate RVA products were poured into disc shapes in circular (1.5 in diameter) plastic sample cups meant for water activity measurement. They were cooled to room temperature and then scooped with a metal spatula onto the center of the rheometer stage surface, making sure to maintain their shape and avoid breakage. The samples meant for "day 7" rheometer analysis were cooled to room temperature, and then covered with lids and sealed with parafilm. They were stored in containers at 4°C for seven days until they were taken out to analyze. Due to the higher deviation between results of the rheometer, each treatment required four samples to be analyzed.

Every day before running samples, the TA Instruments Discovery HR-3 rheometer was calibrated with both rotational and oscillatory mapping. After placing a sample on the stage, the excess edges were trimmed with the "trim gap" function at 50.0 μm and a 40.0 mm parallel plate. If the sample did not fully gelatinize during its RVA run, it would not form a gel after cooling

prior to its rheometer analysis. Because of that, the liquid sample would have to be poured onto the rheometer stage, and the “trim gap” function would have minimal effect on the state of the sample. The trimmed sample was analyzed at a controlled temperature of 25°C and the test strain was set to 0.5%, with an angular frequency of 0.1 rad/s to 100.0 rad/s. The analysis results were in the format of storage modulus and loss modulus versus angular frequency.

Figures and Tables

Table B-1 The starch gelatinization temperature (T_{gel}) and retrogradation, determined by DSC analysis of starch in solutions containing different types and concentrations of sweeteners

	Sweetener Concentration														
	0% w/w			15% w/w			30% w/w			45% w/w			60% w/w		
Sweetener Type	**T_{gel} Onset (°C)**	**Enthalpy Day 0 (J/g)**	**Enthalpy Day7 (J/g)**	**T_{gel} Onset (°C)**	**Enthalpy Day 0 (J/g)**	**Enthalpy Day7 (J/g)**	**T_{gel} Onset (°C)**	**Enthalpy Day0 (J/g)**	**Enthalpy Day7 (J/g)**	**T_{gel} Onset (°C)**	**Enthalpy Day0 (J/g)**	**Enthalpy Day7 (J/g)**	**T_{gel} Onset (°C)**	**Enthalpy Day0 (J/g)**	**Enthalpy Day7 (J/g)**
Glucose	60.71±0.41^{C}	0.047±0.031^{Aa}	1.567±0.147^{Bc}	64.31±0.27^{Aa}	0.109±0.054^{Aa}	1.809±0.155^{Aa}	69.15±0.77^{Bb}	0.072±0.020^{Aa}	1.787±0.293^{Bb}	77.49±0.04^{Bc}	0.0963±0.010^{Aa}	1.399±0.132^{Bb}	-	-	-
Fructose	60.71±0.41^{C}	0.047±0.031^{Aa}	1.567±0.147^{Bc}	63.31±.026^{Aa}	0.035±0.030^{Aa}	2.305±0.093^{Aa}	68.35±0.49^{Bb}	0.151±0.044^{Aa}	2.682±0.389^{Aa}	75.96±0.24^{Cc}	0.030±0.024^{Aa}	2.775±0.099^{Aa}	85.38±1.09^{Bd}	0.178±0.059^{Aa}	3.017±0.857^{Aa}
Invert Sugar	60.71±0.41^{C}	0.047±0.031^{Aa}	1.567±0.147^{Bc}	63.61±0.28^{Aa}	0.044±0.031^{Aa}	2.246±0.494^{Ab}	68.62±0.09^{Bb}	0.084±0.008^{Aa}	2.772±0.159^{Aa}	76.91±0.16^{Cc}	0.071±0.043^{Aa}	2.828±0.475^{Aa}	86.77±0.44^{Bd}	0.025±0.014^{Aa}	3.756±0.062^{Bb}
Sucrose	60.71±0.41^{C}	0.047±0.031^{Aa}	1.567±0.147^{Bc}	65.8±0.3^{Ba}	0.072±0.011^{Aa}	1.933±0.220^{Ab}	72.23±0.24^{Ab}	0.070±0.024^{Aa}	1.807±0.397^{Bb}	82.35±0.3^{Ac}	0.0567±0.049^{Aa}	0.830±0.164^{Bb}	98.49±0.42^{Ad}	0.102±0.034^{Aa}	0.776±0.058^{Cc}

Table B-2 RVA parameters of starch in solutions containing different types and concentrations of sweeteners.

A) Pasting Temperature **(°C)**

Sweetener Type	**0% w/w**	**15% w/w**	**30%w/w**	**45%w/w**	**60%w/w**
Glucose	87.4±0.4^{Ad}	72.4±0.5^{ABa}	76.9±0.5^{ABb}	84.8±0.1^{Bc}	>95
Fructose	87.4±0.4^{Ad}	71.6±0.4^{Ba}	75.3±0.5^{BCb}	82.8±0.5^{Cc}	94.2±0.4^{Ae}
Invert Sugar	87.4±0.4^{Ad}	72.4±0.4^{ABa}	76.15±0.4^{Cb}	84.0±0.0^{BCc}	95.1±0.6^{Ae}
Sucrose	87.4±0.4^{Ac}	73.2±0.4^{Aa}	78.3±0.1^{Ab}	88.3±0.9^{Ac}	>95

B) Peak Viscosity (PV in cP)

Sweetener Type	**0% w/w**	**15% w/w**	**30%w/w**	**45%w/w**	**60%w/w**
Glucose	1534±17^{Ad}	2930±15^{Ac}	4041±36^{Bb}	4836±66^{Ca}	-
Fructose	1534±17^{Ad}	2846±3^{Ac}	4189±32^{Ab}	5655±51^{Aa}	-
Invert Sugar	1534±17^{Ad}	2912±9^{Ac}	4140±21^{ABb}	5285±33^{Ba}	-
Sucrose	1534±17^{Ad}	2714±39^{Bc}	3423±48^{Ca}	3047±58^{Db}	-

C) Trough Viscosity (TV in cP)

Sweetener	0%w/w	15% w/w	**30%w/w**	**45%w/w**	**60%w/w**
Glucose	1305±20^{Ad}	2679±15^{Ac}	3849±59^{Bb}	4802±46^{Ca}	-
Fructose	1305±20^{Ad}	2578±18^{ABc}	4018±15^{Ab}	5560±32^{Aa}	-
Invert Sugar	1305±20^{Ad}	2649±12^{Ac}	3965±14^{ABb}	5249±34^{Ba}	-
Sucrose	1305±20^{Ad}	2496±51^{Bc}	3309±80^{Ca}	3040±60^{Db}	-

D) Breakdown Viscosity (BD in cP)

Sweetener	**0%w/w**	**15% w/w**	**30%w/w**	**45%w/w**	**60%w/w**
Glucose	228±9^{Aa}	251±4^{Aa}	192±36^{Ab}	34±20^{Ac}	-
Fructose	228±9^{Aa}	268±16^{Aa}	171±18^{ABb}	55±20^{Ac}	-
Invert Sugar	228±9^{Aa}	263±9^{Aa}	175±11^{Ab}	36±3^{Ac}	-
Sucrose	228±9^{Aa}	218±12^{Aa}	115±33^{Bb}	7±2^{Ac}	-

E) Setback (SB in cP)

Sweetener	**0%w/w**	**15% w/w**	**30%w/w**	**45%w/w**	**60%w/w**
Glucose	21±16^{Ac}	191±12^{Ab}	293±40^{ABab}	358±59^{Ca}	-
Fructose	21±16^{Ad}	195±12^{Ac}	397±12^{Ab}	763±87^{Aa}	-
Invert Sugar	21±16^{Ad}	172±17^{Ac}	354±7^{Ab}	524±30^{Ba}	-
Sucrose	21±16^{Ac}	158±24^{Aab}	258±11^{Ba}	60±24^{Dbc}	57±3^{Abc}

F) Final Viscosity (FV in cP)

Sweetener	**0%w/w**	**15% w/w**	**30%w/w**	**45%w/w**	**60%w/w**
Glucose	1555±28^{Ad}	3121±7^{Ac}	4334±15^{Bb}	5194±36^{Ca}	-
Fructose	1555±28^{Ae}	3040±10^{Ad}	4586±23^{Ac}	6418±50^{Ab}	7388±101^{Aa}
Invert Sugar	1555±28^{Ae}	3084±20^{Ad}	4494±28^{Ac}	5809±15^{Ba}	5510±94^{Bb}
Sucrose	1555±28^{Ad}	2872±63^{Bc}	3680±48^{Ca}	3107±77^{Db}	-

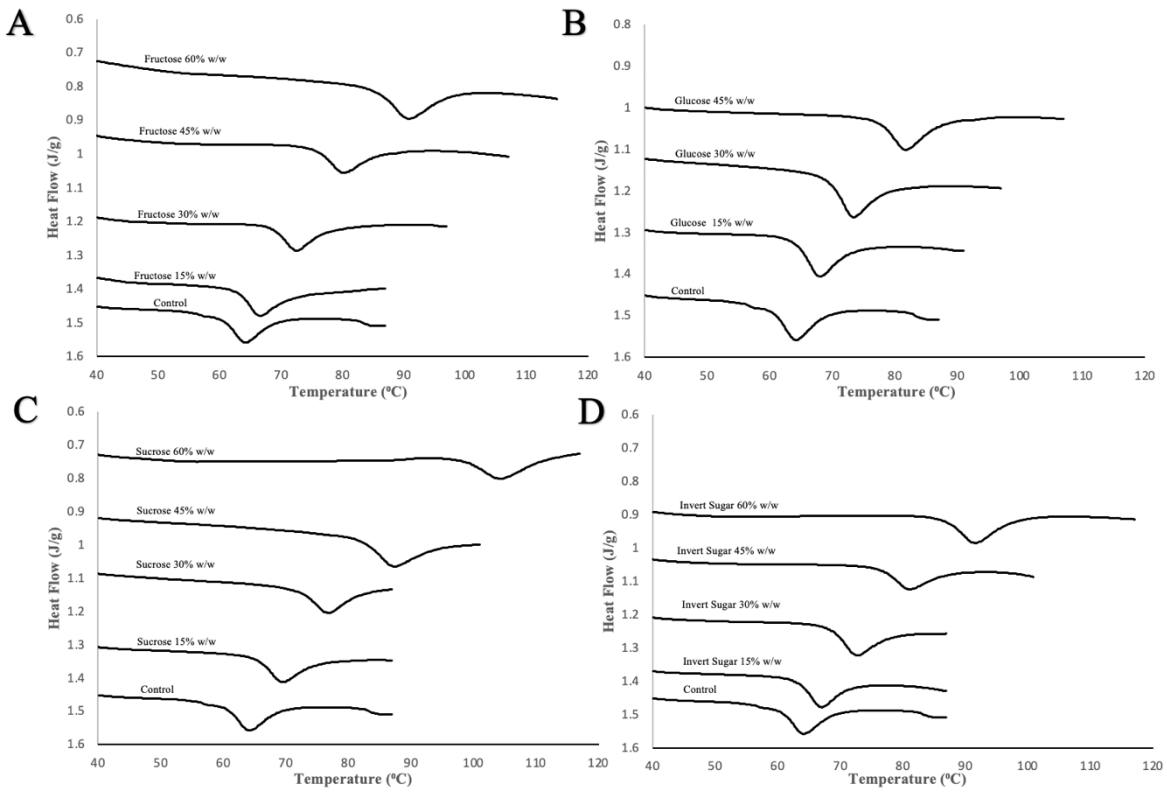


Figure B-6 DSC thermograms of wheat starch in the presence of different types and concentrations of sweeteners.

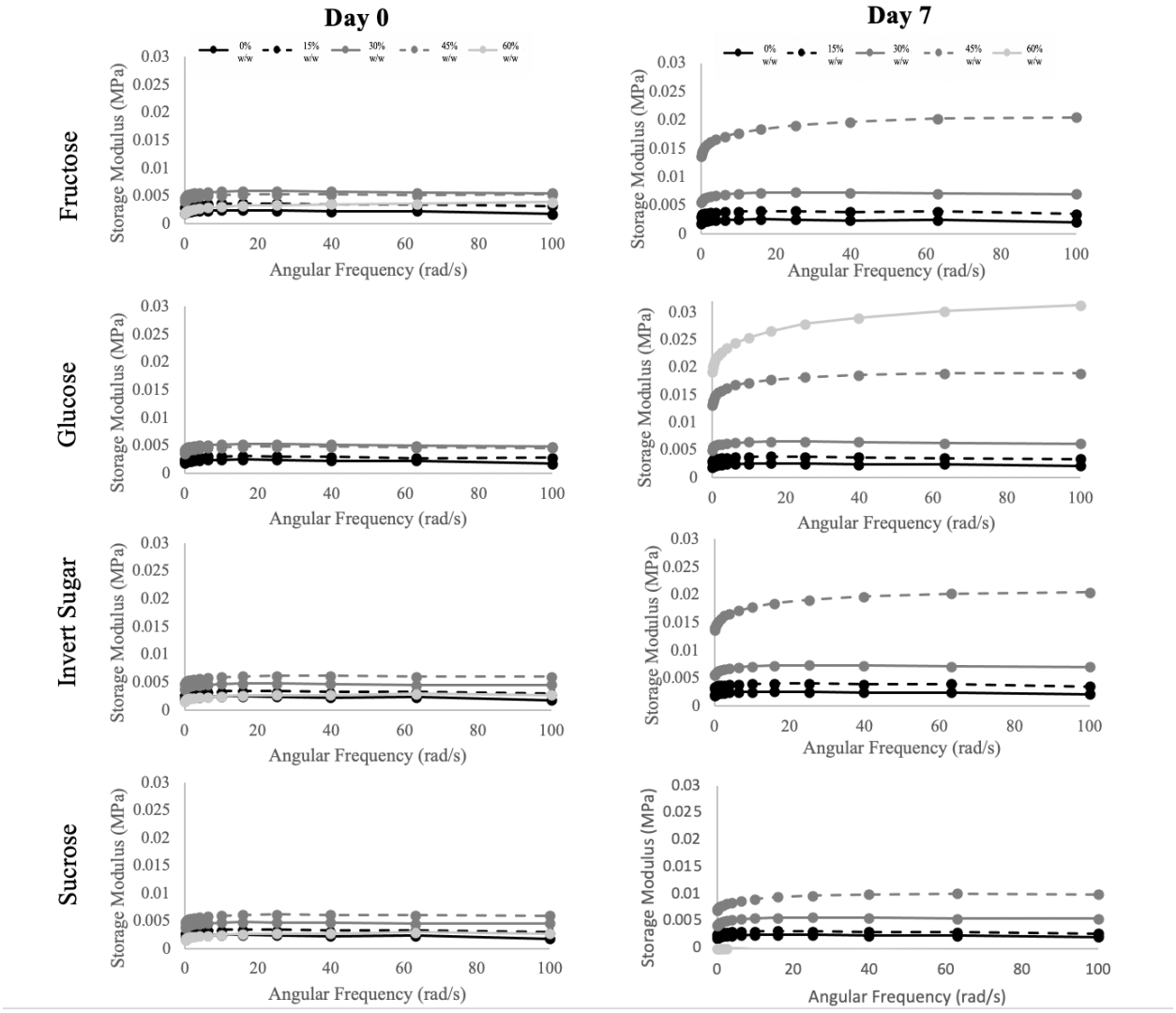


Figure B-7 The storage modulus (MPa) of four different sweetener solution concentrations grouped by sweetener types versus angular frequency (rad/s).

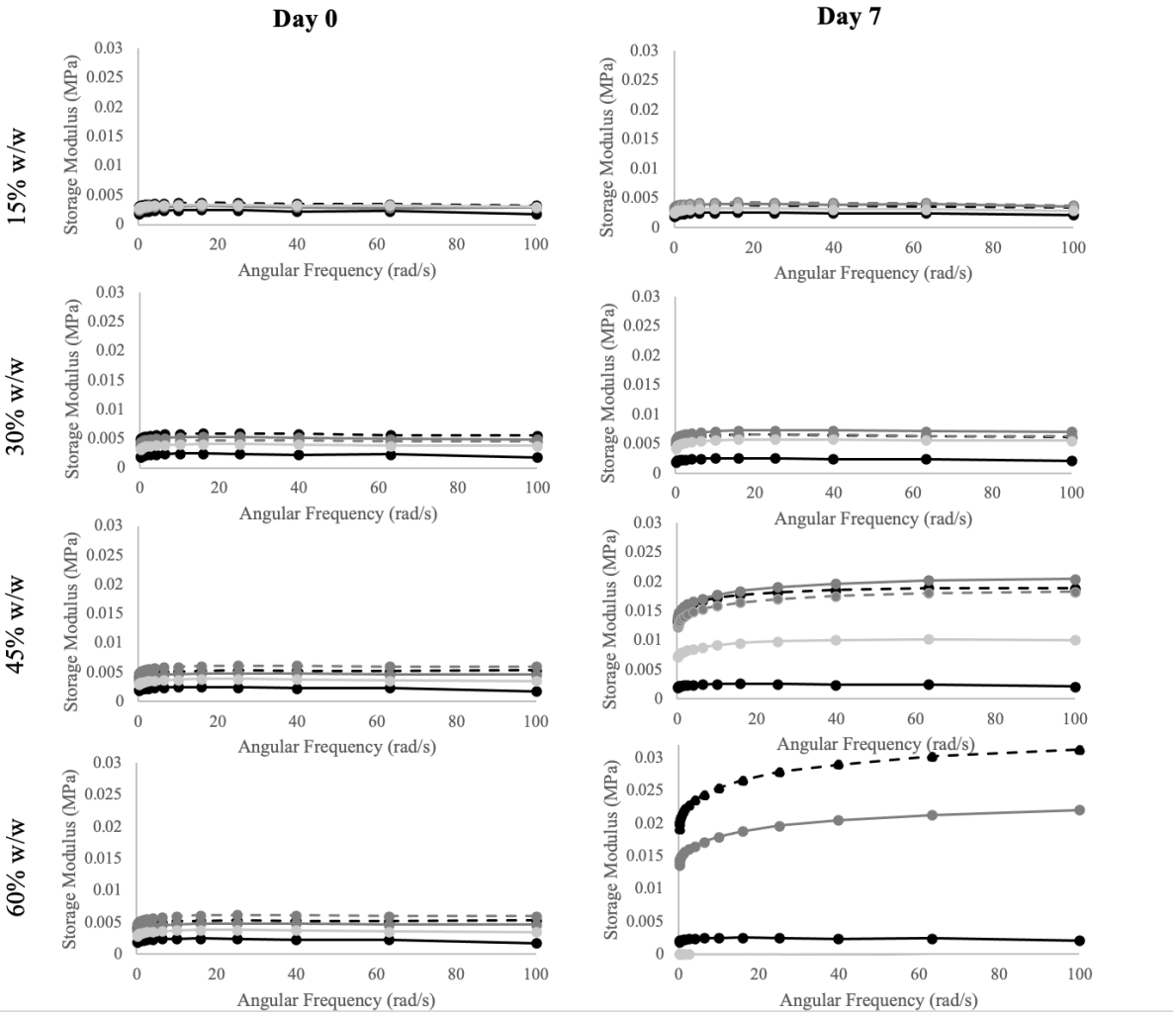


Figure B-8 The storage modulus (MPa) of different sweetener types grouped by sweetener solution concentrations versus angular frequency (rad/s).

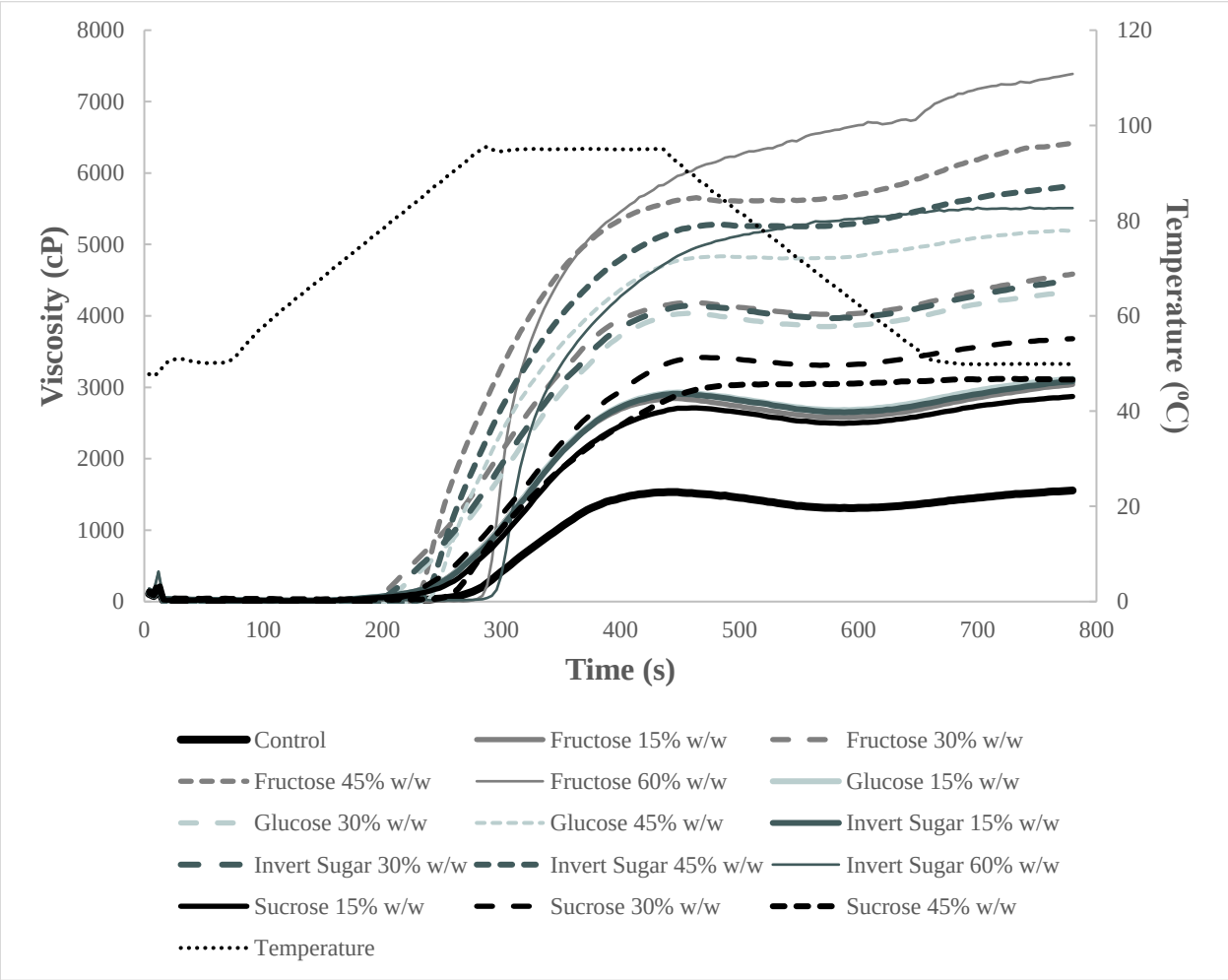


Figure B-9 The effects of sweetener types on concentration (%w/w) on the pasting behavior of wheat starch compared to the control (water).

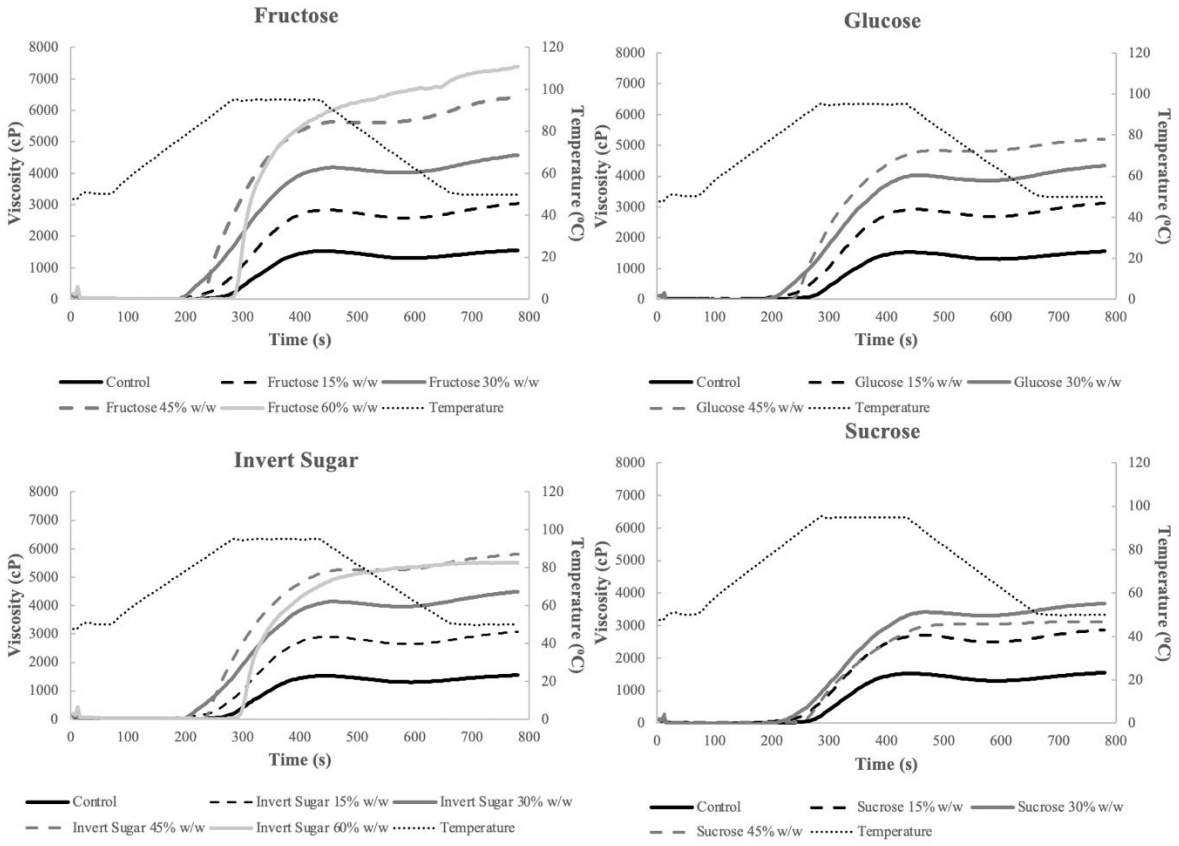


Figure B-10 Concentration effects of sweeteners on pasting behavior of wheat starch in RVA analysis.

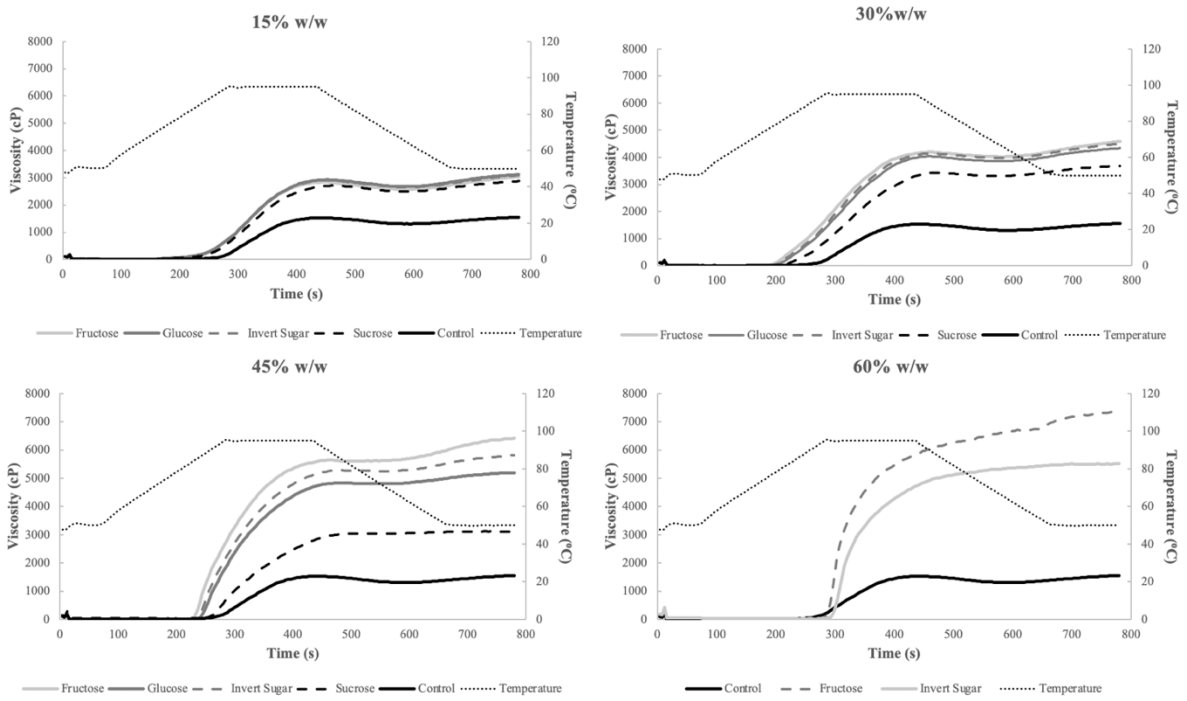


Figure B-11 Sweetener type effects on starch pasting at four concentrations in RVA analysis.

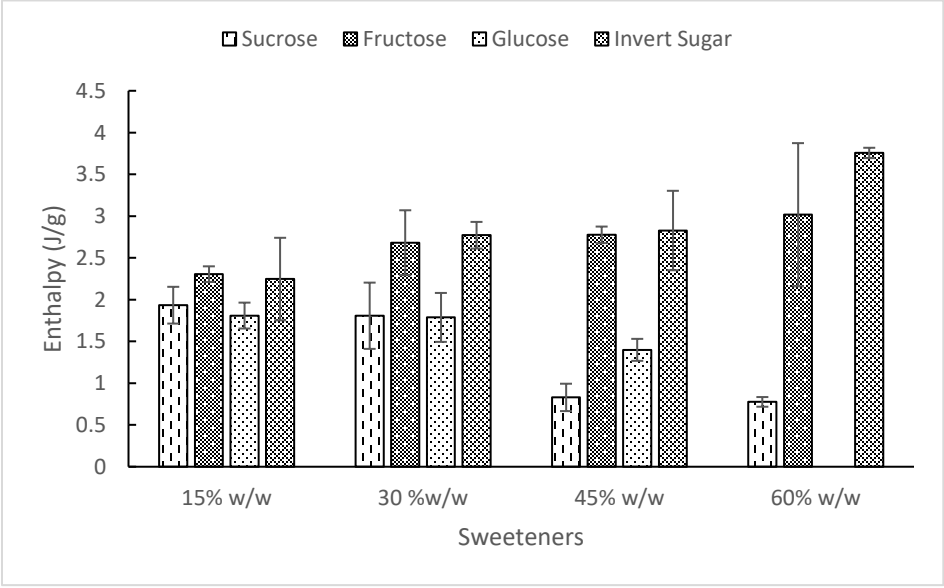


Figure B-12 Retrogradaton enthalpy (J/g) on day 7 of wheat starch in the presence of sweeteners at four concentrations.

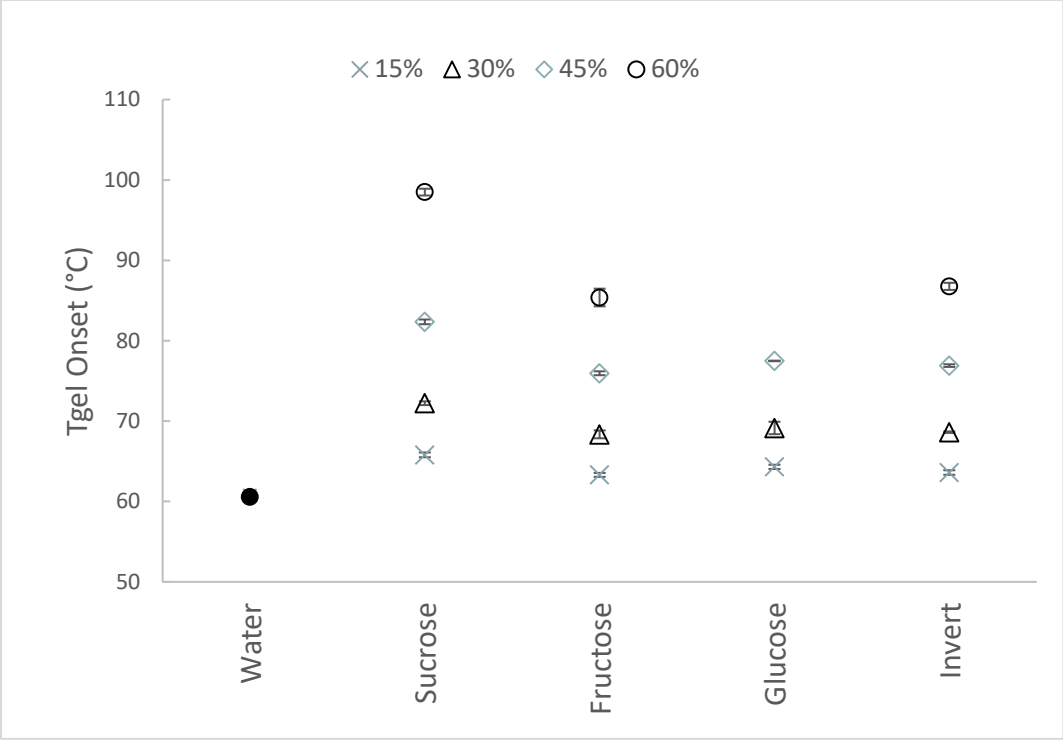


Figure B-13 The onset gelatinization temperature of wheat starch in sweetener solutions grouped by concentration: 15% w/w(x), 30% (Δ), 45% (◊), and 60% (O); and the control with only water.

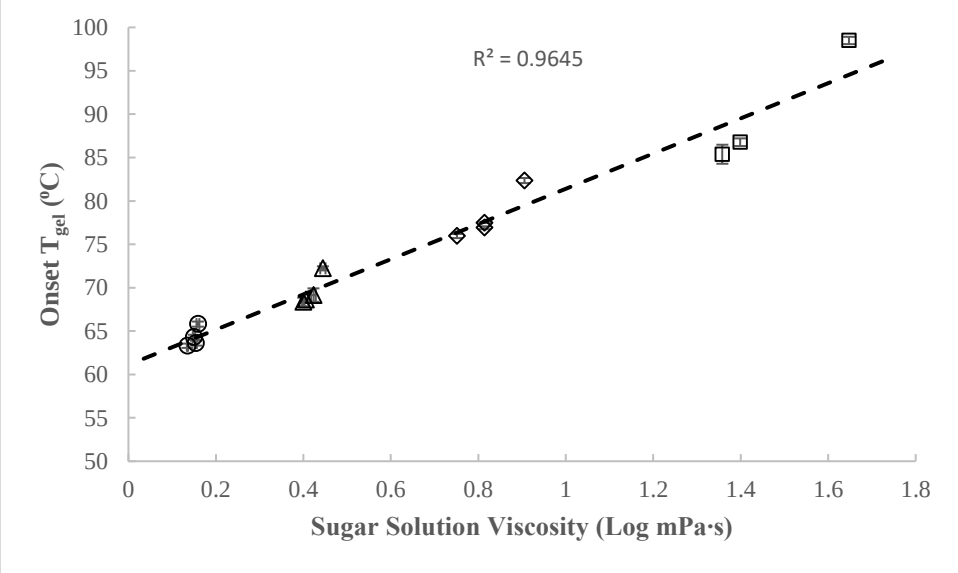


Figure B-14 The effect of sugar solution viscosity on the wheat starch onset gelatinization temperature.

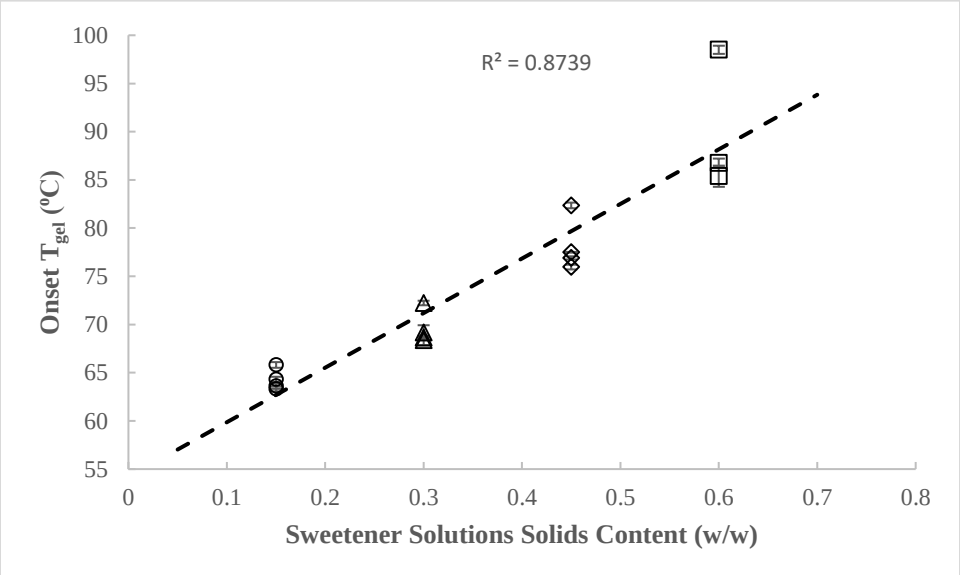


Figure B-15 Effect of sweetener solution solids content on wheat starch onset gelatinization temperature.

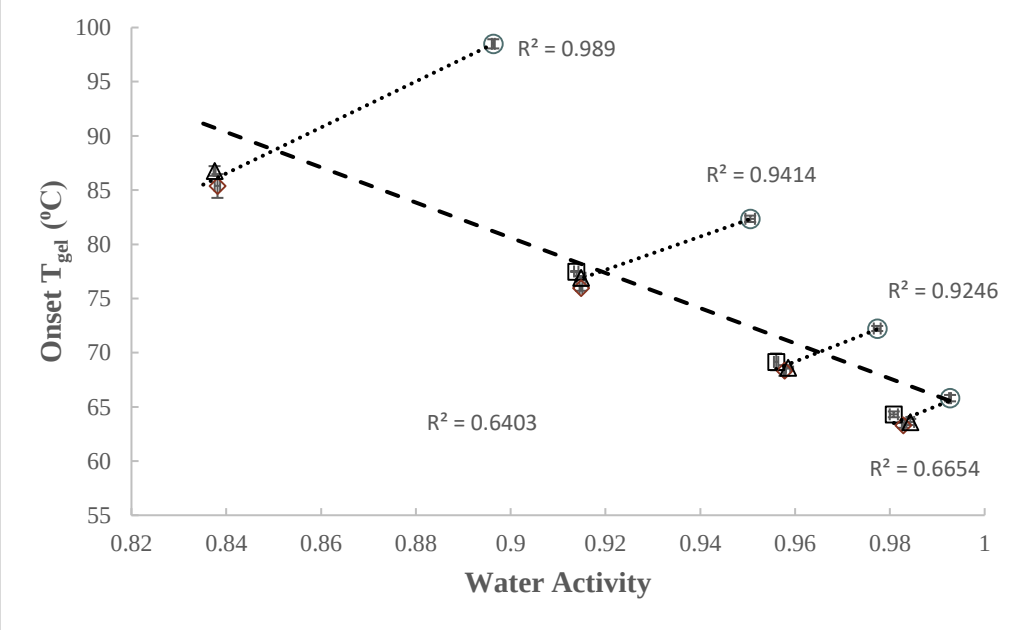


Figure B-16 Effect of aw on wheat starch onset gelatinization temperature.

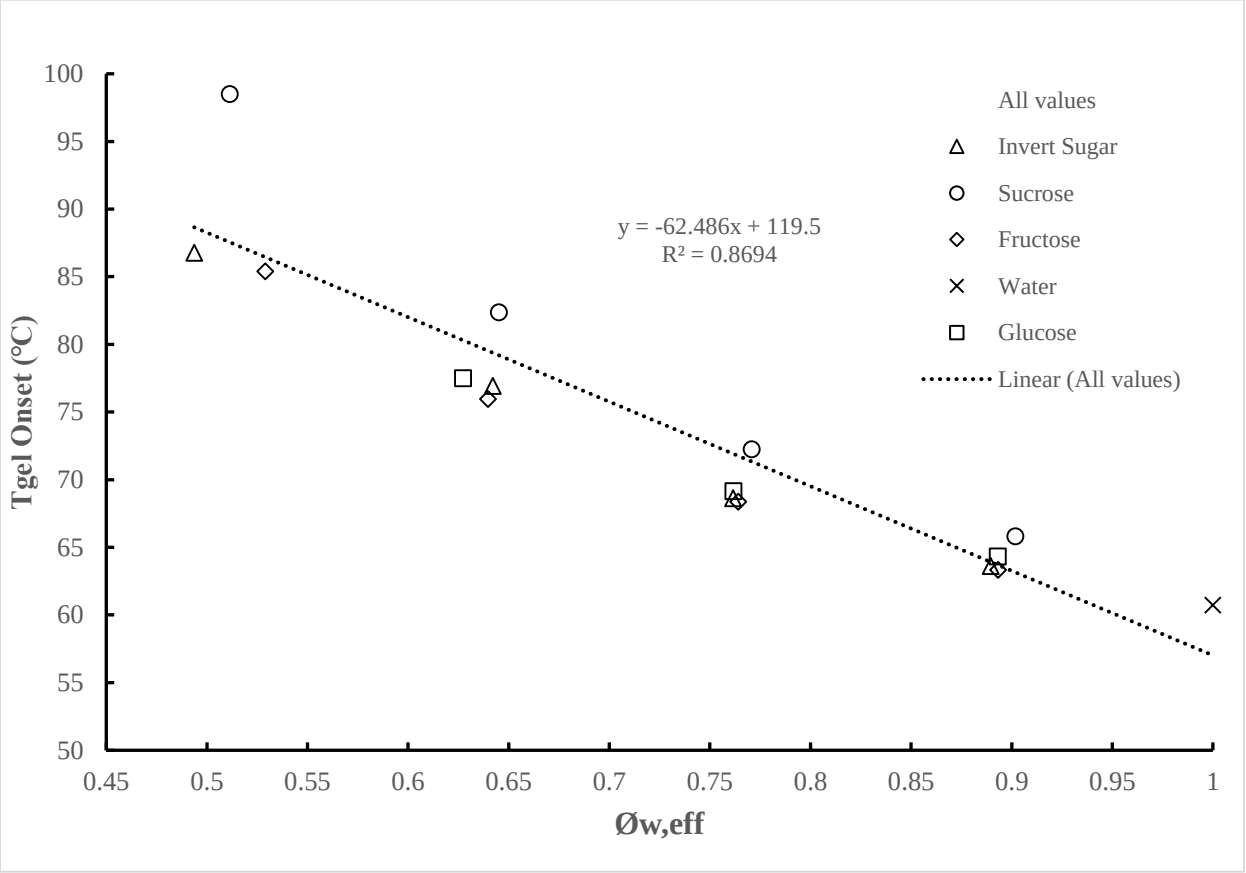


Figure B-17 The relationship between wheat starch onset gelatinization temperature and the sweetner effective volume fraction, Øw,eff .

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