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Assessing Functionality of Alternative Sweeteners in Rolled "Sugar" Cookies

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Abstract: Sucrose contributes to the key physical and sensory characteristics of cookies. Due to the negative health effects associated with excess sucrose consumption, the replacement of sucrose in baking applications is of interest. In this study, nine variations of rolled cookies were prepared ($n = 3$) using a sucrose control (C), Splenda for baking (SB), Equal for baking (EB), Truvia (TR), Sweet'N Low (SNL), and 1:1 (wt%) mixtures of sweeteners and sucrose (S). The cookies were characterized by a width-to-thickness (W/T) ratio, moisture loss, color, hardness, and fracturability. The W/T ratios of TR (5.7) and TR + sucrose (6.6) were similar, the closest to C (7.7), and bigger than ($p < 0.05$) all other treatments. Color was not affected ($p > 0.05$) by the sugar type or concentration. C showed the greatest hardness (5268 N), and SNL had the greatest fracturability (8667 N). Overall, regarding physiochemical characteristics, TR + sucrose (1:1 replacement) and SB (100% replacement) were the closest to the control.

Keywords: alternative sweeteners; sucrose; cookies; baking; sugar reduction

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1. Introduction

Sugar reduction is a current challenge being addressed in the food industry [1]. In 2015, the World Health Organization recommended that the daily consumption of free sugars be reduced to less than 10% of total energy intake to reduce the risk of obesity and dental decay [2]. Current trends show that the average consumption of added sugars is above 10%, except for in the elderly and infants [3]. It is projected that, by the year 2030, 1.12 billion people around the world will be obese if current trends are sustained [4].

As of January 1, 2020, the Food and Drug administration (FDA) requires added sugars to be included in the nutrition facts panel. As defined by the FDA, "added sugars are either added during the processing of foods, or are packaged as such, and include sugars (free, mono and disaccharides), sugars from syrups and honey, and sugars from concentrated fruit or vegetable juices" [5]. Therefore, many consumers are looking to lower the sugar content of their food [6]. In 2021, the International Food Information Council (IFIC) conducted a Food and Health survey that found that 72% of consumers are attempting to reduce their sugar intake [7].

Reducing the sugar content of bakery products presents challenges related to the functionalities provided by sucrose, such as the sensory attributes related to sweetness and mouthfeel, and the physical attributes related to the texture, color, and processing parameters of the dough [1]. Cookies typically have a high sugar content comprising 30–40% of the formula. Sugar is a key ingredient in rolled cookie formulations, with sucrose commonly being used in traditional recipes [8]. Sucrose granules in cookie dough dissolve with the heat of baking. This fluidity causes the cookies to spread in the oven, with higher concentrations of sucrose correlating with a greater spread [9]. Cookies expand in the oven, followed by a structural collapse and the recrystallization of dissolved sucrose upon drying and cooling. These phenomena are believed to give sugar snap cookies their characteristic cracked appearance on the top [9,10]. Sucrose also contributes to the formation of a golden brown color through browning reactions [11]. These characteristics determine the final product quality of sugar-snap cookies, including their crisp texture and storage stability [10].

The commercially relevant non-caloric sweeteners used as sugar alternatives include sucralose, aspartame, acesulfame potassium (Ace-K), saccharine, and plant-based sweeteners (such as stevia) [1]. Maltodextrin, sugar alcohols, and fibers can be used as bulking agents in the preparation of high-intensity sweeteners as a method to reduce sugar in baked goods [12]. In a study by Ho and Pulsawat, 2020, sugar was partially replaced at the 50% level with either maltitol, sorbitol, or isomalt [13]. It was noted that all treatments could reduce sugar and daily calorie intake, with maltitol and isomalt yielding similar sensory attributes to the control. In a review by Luo et al., 2019, maltitol served as a single substitute for sucrose in baked goods [14]. Natural products also have the benefit of serving as bulking agents or providing sweetness in baked goods. Dates may be added to baked goods to provide both sweetness and fiber as a bulking agent [15]. Apple pomace flour (APF) has been studied as a product high in dietary fibers that could be added to cookies with an acceptable flavor and texture profile. Therefore, APF may serve as a fiber/bulking agent for a low-sugar cookie [16]. Another natural approach to incorporating bulking agents in low-sugar cookies could be through the addition of high fiber flours. In 2021, Pavičić et al. found that the inclusion of carob, oat, or rye flours reduced the spread of 3D printed cookies with olive oil [17].

It is suggested that non-nutritive sweeteners in combination with polyols and bulking agents can be used to reduce sugar in baked goods. More research is needed to determine the minimum sugar level and/or sugar substitution levels to maintain similar functional properties in baked goods [14]. Therefore, the objective of our study was to determine the effect of different alternative sweeteners that contained sugar alcohols or bulking agents at 100% and 50% replacement on the physiochemical properties of rolled “sugar” cookies.

2. Materials and Methods

2.1. Experimental Design

The experiment consisted of nine treatments: sucrose control (C), Splenda for baking (SB), Equal for baking (EB), Truvia (TR), Sweet’N Low (SNL), and mixtures of Splenda for baking and sucrose (SB + S), Equal for baking and sucrose (EB + S), Truvia and sucrose (TR + S), and SNL and sucrose (SNL + S). The ingredients in each commercially available artificial sweetener are given in Tables 1 and 2. The individual and mixture amounts were determined based on relative sweetness values. The Baker’s Percentages are given in Tables 1 and 2. The experiment was performed in triplicate (n = 3).

Alternative sweeteners were chosen from commercially available sources. Splenda for baking is made up of sucralose, a popular sugar alternative in baked goods, and maltodextrin, a bulking agent. Equal for baking includes aspartame, acesulfame potassium (Ace-K), and maltodextrin for bulking. Sweet’N Low for Baking was selected as aspartame is a popular sugar-free sweetener for beverages, but it is not heat stable and, therefore, has limited applications in baked foods. To improve functionality in baked goods, maltodextrin is added for bulking and acesulfame potassium is added to assist with heat stability. Truvia, composed of stevia and erythritol, is an all-natural sugar alternative with a sugar alcohol added for functional benefits. Sweet’N Low is made up of saccharin and nutritive dextrose as the bulking agent.

Table 1. Formulation of cookies with 100% sucrose replacement based on relative sweetness level.

Ingredient and Supplier	Baker's Percent (Flour Weight Basis)				
	Control (C)	Splenda for Baking (SB)	Equal for Baking (EB)	Truvia (TR)	Sweet'N Low (SNL)
All-Purpose Flour (bleached wheat flour, malted barley flour, niacin, iron (reduced), thiamine mononitrate, riboflavin, folic acid) (Great Value, Walt-Mart Stores, Inc., Bentonville, AR, USA)	100	100	100	100	100
Shortening (soybean oil, hydrogenated palm oil, palm oil, mono and diglycerides, TBHQ, citric acid) (The Kroger Co., Cincinnati, OH, USA)	28.4	28.4	28.4	28.4	28.4
Sugar (Great Value, Wal-Mart Stores, Inc., Bentonville, AR, USA)	57.8	-	-	-	-
Splenda for Baking (maltodextrin, sucralose) (McNeil Nutritionals LLC, Fort Washington, PA, USA)	-	7.2	-	-	-
Equal for Baking (maltodextrin, aspartame, acesulfame potassium) (Merisant US, Inc., Chicago, IL, USA)	-	-	6.8	-	-
Truvia (erythritol, stevia leaf extract, natural flavors) (Cargill, Inc., Minneapolis, MN, USA)	-	-	-	26.7	-
Sweet'N Low (nutritive dextrose, saccharin, cream of tartar, calcium silicate) (Cumberland Packing Corp., Brooklyn, NY, USA)	-	-	-	-	7.1
Iodized Salt (salt, calcium silicate, dextrose, potassium iodide) The Kroger Co., Cincinnati, OH, USA	0.9	0.9	0.9	0.9	0.9
Sodium Bicarbonate (Arm & Hammer, Church & Dwight, Co., Inc., Ewing, NJ, USA)	1.1	1.1	1.1	1.1	1.1
Dextrose Solution (8.9 g dextrose in 150 mL water) (STALEYDEX 333, Tate & Lyle, Decatur, IL, USA)	14.7	14.7	14.7	14.7	14.7
Water (high concentration) Municipal water, Manhattan, KS, USA	-	28.4	28.4	28.4	28.4
Water (low concentration) Municipal water, Manhattan, KS, USA	7.1	-	-	-	-

Table 2. Formulation of cookies with 1:1 sucrose to sweetener based on relative sweetness level.

Ingredient and Supplier	Baker's Percent				
	Control (C)	Splenda for Baking + Sucrose (SB + S)	Equal for Baking + Sucrose (EB + S)	Truvia + Sucrose (TR + S)	Sweet'N Low + Sucrose (SNL + S)
All-Purpose Flour (bleached wheat flour, malted barley flour, niacin, iron (reduced), thiamine mononitrate, riboflavin, folic acid) (Great Value, Walt-Mart Stores, Inc., Bentonville, AR, USA)	100	100	100	100	100
Shortening (soybean oil, hydrogenated palm oil, palm oil, mono and diglycerides, TBHQ, citric acid) (The Kroger Co., Cincinnati, OH, USA)	28.4	28.4	28.4	28.4	28.4
Sugar (Great Value, Wal-Mart Stores, Inc., Bentonville, AR, USA)	57.8	28.9	28.9	28.9	28.9
Splenda for Baking (maltodextrin, sucralose) (McNeil Nutritionals LLC, Fort Washington, PA, USA)	-	3.6	-	-	-
Equal for Baking (maltodextrin, aspartame, acesulfame potassium) (Merisant US, Inc., Chicago, IL, USA)	-	-	3.4	-	-
Truvia (erythritol, stevia leaf extract, natural flavors) (Cargill, Inc., Minneapolis, MN, USA)	-	-	-	13.3	-
Sweet'N Low (nutritive dextrose, saccharin, cream of tartar, calcium silicate) (Cumberland Packing Corp., Brooklyn, NY, USA)	-	-	-	-	3.6
Iodized Salt (salt, calcium silicate, dextrose, potassium iodide) The Kroger Co., Cincinnati, OH, USA	0.9	0.9	0.9	0.9	0.9
Sodium Bicarbonate (Arm & Hammer, Church & Dwight, Co., Inc., Ewing, NJ, USA)	1.1	1.1	1.1	1.1	1.1
Dextrose Solution (8.9 g dextrose in 150 mL water) (STALEYDEX 333, Tate & Lyle, Decatur, IL, USA)	14.7	14.7	14.7	14.7	14.7
Water (high concentration) Municipal water, Manhattan, KS, USA	-	28.4	28.4	28.4	28.4
Water (low concentration) Municipal water, Manhattan, KS, USA	7.1	-	-	-	-

2.2. Materials

All ingredients were purchased from a local store. Procedures and formulations were adapted from the American Association of Cereal Chemists (AACC) Method 10-50.05: Baking Quality of Cookie Flour (AACC International, 1999). Ingredients, suppliers, and formulations can be found below (Tables 1 and 2). Two water concentrations were used in the cookie formulations. A low concentration was used for the control, resulting in a non-sticky dough. Extra water was required for the alternative sweetener treatments to allow for the desired consistency for the rolling of the modified cookie dough. Without the extra addition of water, alternative sweetener formulations formed crumbly mixtures that could not be formed into cookies.

2.3. Cookie Preparation

The equipment needed to prepare the cookies included scales (Ohaus, Parsippany, NJ, USA), weigh boats, spoons, disposable pipettes, spatulas, a stand mixer with a flat paddle attachment (KitchenAid Artisan, Model No. KSM150PSWH, St. Joseph, MI, USA), a rolling pin, a 7.5 cm circular cookie cutter, 7 mm-diameter wooden dowel rods, parchment paper (Reynolds Consumer Products LLC, Lake Forest, IL, USA), plastic wrap (Handi-Film, Handi-foil of America Inc., Wheeling, IL, USA), baking sheets (The Vollrath Co., L.L.C., Sheboygan, WI; USA PAN, Crescent, PA, USA), ovens (Whirlpool Model RF367LXSB, Benton Harbor, MI, USA), cooling racks, and low-density polyethylene (LDPE) bags (Ziploc, SC Johnson, Racine, WI, USA).

The analytical equipment needed to collect data included digital calipers (Tool Shop, Eau Claire, WI, USA), standard rulers with cm/mm, a portable HunterLab MiniScan colorimeter (Model No. 4500L, Reston, VA, USA), a Texture Technologies Corp texture analyzer with a 30 kg load cell and a flat blade attachment (TA-XT2, Scarsdale, NY, USA), and Exponent Stable Micro Systems texture analysis software (Godalming, UK).

Shortening, sweetener(s), salt, and sodium bicarbonate were creamed in a stand mixer (KitchenAid Artisan, Model No. KSM150PSWH, St. Joseph, MI) for 3 min on Speed 2, pausing to scrape the sides of the bowl every 1 min. Dextrose solution and water were added and mixed on Speed 1 for 1 min and then for 1 min more on Speed 4, stopping in between to scrape the bowl. Flour was then added and mixed for 2 min on Speed 2, scraping the bowl every 30 s.

The dough was removed from the bowl and placed between two pieces of plastic wrap. Two 7 mm-diameter wooden dowel rods were taped to a clean countertop 18 cm apart so that the entire width of the rolling pin rested on top of them. The dough was rolled to a 7 mm thickness, using the dowel rods as guides. The cookies were cut using a 7.5 cm circular cookie cutter. The dough was rerolled up to two times to obtain as many cookies as possible from the dough to prevent overworking. The cookies were baked for 10 min in a preheated oven at 204.4 °C. The cookies were allowed to cool at room temperature approximately 30 min before they were placed in LDPE bags and frozen at −20 °C overnight so that all samples could be analyzed at the same time. The cookies were allowed to thaw approximately 1 h before analyzing.

2.4. Physical Analyses

2.4.1. Spread

The cookie spread was measured using a method adapted from the AACC Method 10-50.05: Baking Quality of Cookie Flour (AACC International, 1999). Three cookies were placed edge to edge, and the width was measured to the nearest 0.1 mm using digital calipers (Tool Shop, Eau Claire, WI, USA). The cookies were then rotated 90°, and the width was measured again. The average width was calculated. The same three cookies were then stacked on top of one another, and the thickness (height) of the stack was measured in mm. The stack of cookies was shuffled, and the thickness was measured again. The average thickness was calculated from the two thickness values. Then, the average width and average thickness were used to calculate the width-to-thickness (W/T) ratio (Equation (1)).

$$W/T = \frac{\text{Average width of 3 cookies}}{\text{Average thickness of 3 cookies}} \tag{1}$$

2.4.2. Moisture Loss

Moisture loss was determined using a method adapted from the AACC Method 44-01.01: Calculation of Percent Moisture (AACC International, 1999) to ensure that the amount of water added to the raw dough in all treatments did not significantly affect the final cooked dough product. The baking sheet was first tared on a scale (Ohaus I-20W Model B10AS, Parsippany, NJ, USA). The cut cookies were placed on the baking sheet, and their weight was recorded. After baking, the cookies were allowed to cool slightly before their final weight was recorded. These values were used to calculate the percent moisture loss that occurred during baking (Equation (2)).

$$\text{Percent Moisture loss} = \frac{\text{Weight raw cookies} - \text{Weight baked cookies}}{\text{Weight raw cookies}} \times 100 \tag{2}$$

2.4.3. Color

A portable HunterLab MiniScan colorimeter (Model No. 4500L, Reston, VA, USA) was calibrated using the standardized methods provided by Hunter Associates Laboratory, Inc., (Reston, VA, USA) using a black glass and white tile. Using the colorimeter, the top L*a*b* color of one cookie from each replication was collected. Using the collected L*a*b* values, the total color change (ΔE) was calculated (Equation (3)).

$$\Delta E = \sqrt{\left(L^{*2} a^{*2} b^{*2}\right)} \tag{3}$$

2.4.4. Texture Profile Analysis (TPA)

Texture profile analysis was performed on two cookies per treatment from each replication. The cookies were analyzed for their hardness and three-point fracturability with a calibrated Texture Technologies Corp texture analyzer with a 1 kg load cell and a flat blade attachment (TA-XT2, Scarsdale, NY, USA) and Exponent Stable Micro Systems texture analysis software (Godalming, UK) by following the method settings suggested by the manufacturer (Texture Analysis Application Areas, n.d.). A flat blade attachment was attached to the texture analyzer, and a probe was set to 25% strain. The cookies were placed on a support with a separation of 20 cm. Two compressions of the cookies were performed consecutively. Hardness was measured as maximum force at the first compression, and snapping force was measured as the amount of force required to fracture the cookie.

2.4.5. Nutrition Profile Calculations

For each formulation, Genesis R&D Food Development and Labeling Software from ESHA Research (Salem, OR, USA) was used to estimate the nutrition profile of the cookie treatments. Moisture loss during baking for each treatment was inputted into Genesis. Nutrition facts panels were generated for each formulation, as well as calories (kCal), protein, fat, carbohydrates, and added sugar per 100 g of cookie. A 100 g portion was used to allow comparison among treatments, as treatments varied in average cookie weights after baking.

2.4.6. Student Cookie Attribute Scoring

To understand the trends of the attributes, a group of 60 undergraduate students scored cookies on appearance, texture, flavor, sweetness, and aftertaste. Whole cookies from each treatment were placed on white plates for students to observe the appearance of each treatment. Students then consumed a small piece of one cookie from each treatment and rated each characteristic from 1 to 9 (1 = dislike extremely, 9 = like extremely). Students were provided water between sampling treatments. The samples were not blinded, meaning students knew which treatments they were rating. This may have contributed to some bias in the results but provides trends on cookie treatment attributes.

2.4.7. Statistical Analysis

Data were compiled, and the effects of the treatments were analyzed for their significance using one-way ANOVA followed by Tukey's multiple comparison test. An alpha level of 0.05 was used for all statistical analyses. All the statistical analyses were performed using Minitab 18© Software (State College, PA, USA).

3. Results and Discussion

3.1. Appearance

The type of sweetener affected the visual appearance of the cookies (Figure 1). The control cookies had a cracked and flat top typical for sugar-snap cookies. Sucrose crystallization causes the cookie's surface to dry and break as the cookie continues to expand during baking, producing the typical, cracked appearance of sugar cookies after baking [18]. The cookie formulations with alternative sweeteners yielded cookies with uneven, uncracked top surfaces after baking, and the cookies appeared thicker, except for treatment TR + S, which produced cookies with a more even surface. The uneven surface appearance was probably related to the higher initial moisture content of the alternative sweetener doughs compared to the control. The surface moisture lost during baking is replaced by the water that diffuses from the center of the cookie [18]. However, sucrose is able to recrystallize at the cookie's surface and no longer holds moisture at the cookie's surface. Alternative sweeteners are not able to recrystallize and continue to hold water on the cookie's surface, producing cookies without cracked surfaces. Indeed, at a similar moisture content, the presence of sucrose helped to obtain the desired surface appearance (samples e–f in Figure 1).

3.2. Spread

Cookie spread was measured using the W/T ratio. The treatment with the largest W/T ratio, and thus the largest spread, was C (7.7), followed by TR + S (6.6) and TR (5.7) (Table 3). C was bigger ($p < 0.05$) than all other treatments, while TR and TR + S were statistically similar and the closest to C, but they were significantly different from all the other treatments. This was probably related to the presence of sugar alcohol, erythritol, as a bulking agent in TR.

Table 3. Means and standard deviations for width-to-thickness ratios of each treatment.

Factor [1]	Controlled Mean
C	7.7 ± 0.5^{a}
SB	4.5 ± 0.3^{c}
EB	4.3 ± 0.4^{c}
TR	5.7 ± 0.4^{b}
SNL	4.2 ± 0.2^{c}
SB + S	4.5 ± 0.4^{c}
EB + S	4.5 ± 0.2^{c}
TR + S	6.6 ± 0.2^{b}
SNL + S	4.4 ± 0.2^{c}

[a–c] Tukey pairwise comparisons appear as superscripts by each mean. Means within a column that share a letter are not significantly different ($p > 0.05$). [1] C = control; SB = Splenda for baking; EB = Equal for baking; TR = Truvia; SNL = Sweet'N Low; SB + S = Splenda for baking + sucrose; EB + S = Equal for baking + sucrose; TR + S = Truvia + sucrose; SNL + S = Sweet'N Low + sucrose.

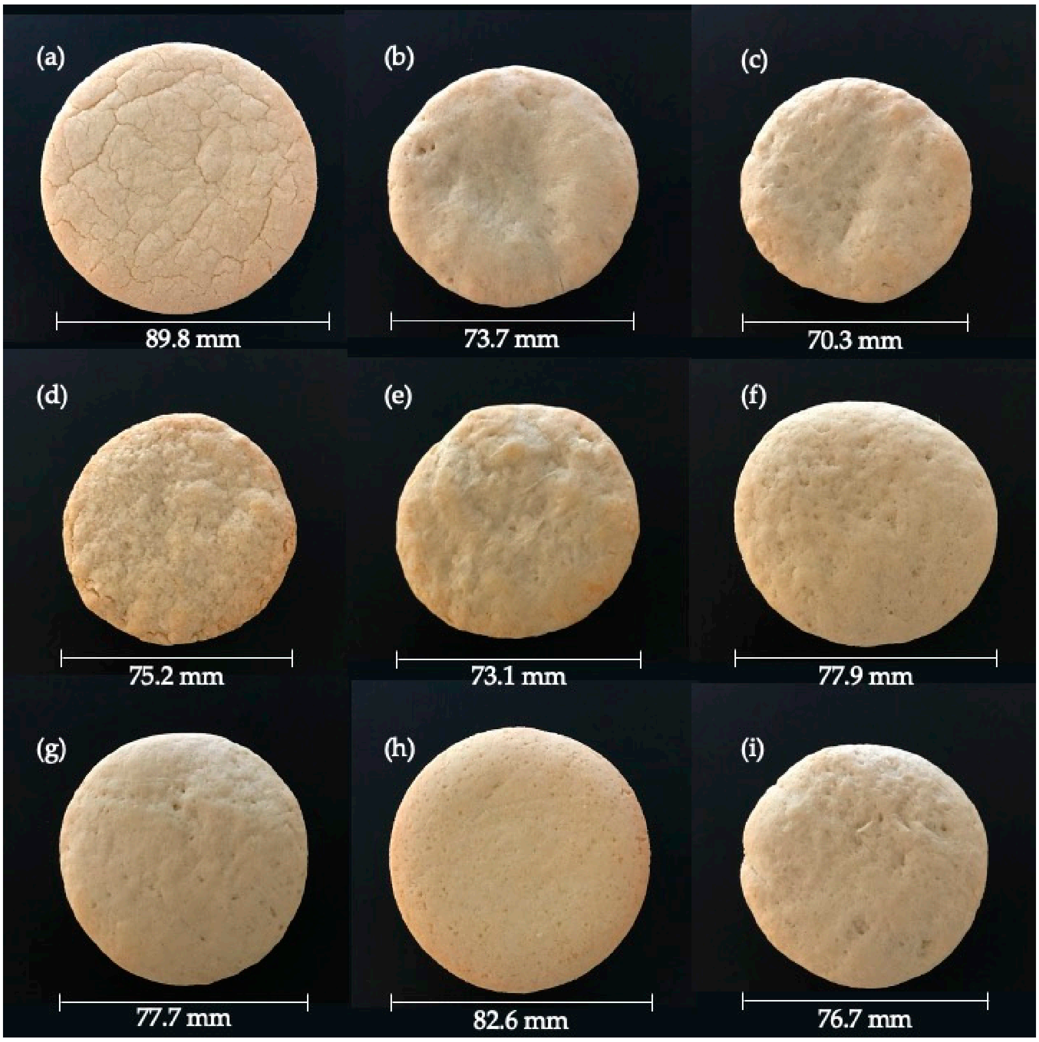

Figure 1. Top images of cookies from each treatment: control (**a**), Splenda for baking (**b**), Equal for baking (**c**), Truvia (**d**), Sweet'N Low (**e**), Splenda + sucrose (**f**), Equal + sucrose (**g**), Truvia + sucrose (**h**), Sweet'N Low + sucrose (**i**).

As the sucrose content in cookies increases, so does the diameter [8,9,19]. Sucrose slowly dissolves throughout the baking time, leading to an improved spread compared to sweeteners that are fully dissolved prior to baking [9]. The crystals of some alternative sweeteners do not share sucrose's ability to spread cookies during the baking process [20]. As the amount of dietetic sweeteners (mannitol and sorbitol) in cookies increases, the width of the cookies decreases [21].

3.3. Moisture Loss

Moisture loss among all treatments was not significant ($p > 0.05$). However, because alternative sweetener doughs required more water, the final moisture content was higher for all artificial sweetener treatments (Table 4). The moisture loss ranged from 5.34 to 6.58%.

Table 4. Means and standard deviations for percent moisture loss of each treatment.

Factor [1]	Controlled Mean
C	6.55 ± 0.27 [a]
SB	6.05 ± 0.32 [a]
EB	5.92 ± 0.99 [a]
TR	5.34 ± 0.32 [a]
SNL	5.51 ± 0.39 [a]
SB + S	6.58 ± 0.63 [a]
EB + S	6.28 ± 0.41 [a]
TR + S	6.58 ± 0.65 [a]
SNL + S	6.81 ± 0.77 [a]

[a] Tukey pairwise comparisons appear as superscripts by each mean. Means within a column that share a letter are not significantly different ($p > 0.05$). [1] C = control; SB = Splenda for baking; EB = Equal for baking; TR = Truvia; SNL = Sweet'N Low; SB + S = Splenda for baking + sucrose; EB + S = Equal for baking + sucrose; TR + S = Truvia + sucrose; SNL + S = Sweet'N Low + sucrose.

3.4. Color

Treatments C (80.842) and SNL + S (83.208) provided the only samples that had a difference in ΔE that was statistically significant ($p < 0.05$) (Table 5). Sucrose participates in the Maillard browning reaction by breaking down into reducing sugars fructose and glucose and reacting with amino acids present during baking [11,22]. Treatment SNL + S contains dextrose, which participates in browning along with the additional sucrose. The other treatments contain either maltodextrin or sugar alcohols as bulking agents that do not participate in browning.

Table 5. L*a*b*, ΔE, and standard deviations for each treatment.

Factor [1]	L*	a*	b*	ΔE
C	76.160 ± 1.690	4.383 ± 1.865	26.607 ± 1.188	80.842 ± 0.854 [b]
SB	77.927 ± 0.567	0.080 ± 0.525	24.623 ± 1.919	81.738 ± 1.022 [a,b]
EB	78.283 ± 0.045	0.257 ± 0.297	24.817 ± 0.641	82.125 ± 0.165 [a,b]
TR	77.757 ± 2.134	1.757 ± 0.272	25.737 ± 1.831	81.948 ± 1.449 [a,b]
SNL	77.773 ± 0.665	1.353 ± 0.140	25.340 ± 1.140	81.815 ± 0.531 [a,b]
SB + S	78.440 ± 0.857	0.150 ± 0.464	26.380 ± 0.427	82.759 ± 0.905 [a,b]
EB + S	78.930 ± 0.860	0.113 ± 0.356	25.360 ± 0.646	82.907 ± 0.766 [a,b]
TR + S	76.470 ± 1.469	4.080 ± 0.870	28.770 ± 0.944	81.816 ± 1.001 [a,b]
SNL + S	78.627 ± 0.788	0.837 ± 0.605	27.170 ± 1.943	83.208 ± 0.939 [a]

[a, b] Tukey pairwise comparisons appear as superscripts by each mean. Means within a column that share a letter are not significantly different ($p > 0.05$). [1] C = control; SB = Splenda for baking; EB = Equal for baking; TR = Truvia; SNL = Sweet'N Low; SB + S = Splenda for baking + sucrose; EB + S = Equal for baking + sucrose; TR + S = Truvia + sucrose; SNL + S = Sweet'N Low + sucrose

3.5. Texture Profile Analysis

The hardness of C (5268 N) was significantly higher ($p < 0.05$) than that of the other treatments (1055–3140 N), likely due to the final moisture content (Table 6). This is consistent with the results from previous studies, where the replacement of sucrose with erythritol in cookies resulted in no significant difference in hardness [23]. In a similar study, it was observed that a 50% replacement of sucrose with sugar alcohols (maltitol, sorbitol, or isomalt) produced cookies with similar textural properties to a control cookie [13]. Harder cookies require less force to fracture because they lack the flexibility of soft cookies. SNL had the greatest fracturability value (8667 N), and TR + S had the lowest fracturability value (2558 N) (Table 6). Regarding three-point fracturability, all partial sucrose replacement treatments (SB + S, EB + S, TR + S, and SNL + S) were statistically similar to C, SB, and TR. Of the total sucrose replacement treatments, only the three-point fracturability values for EB and SNL were significantly different from those of C. It could be hypothesized that these treatments are softer because of the level of maltodextrin or dextrose in the commercial alternative sweeteners used. In 2003, Gallagher et al. found that a relatively low replacement of sugar with raftilose®, an oligosaccharide, resulted in significantly softer cookies [24].

Table 6. Means and standard deviations for hardness and three-point fracturability of each treatment.

Factor [1]	Hardness (N)	Three-Point Fracturability (N)
C	5268 ± 1892 [a]	3561 ± 1351 [c]
SB	1649 ± 226 [b]	5342 ± 1099 [b,c]
EB	1665 ± 208 [b]	7802 ± 441 [a,b]
TR	3140 ± 525 [a,b]	2699 ± 524 [c]
SNL	2058 ± 186 [b]	8667 ± 2345 [a]
SB + S	1093.6 ± 89.6 [b]	3022 ± 819 [c]
EB + S	1055 ± 175 [b]	3193 ± 980 [c]
TR + S	2800 ± 621 [b]	2558 ± 272 [c]
SNL + S	1296.6 ± 79.8 [b]	4429 ± 639 [c]

[a–c] Tukey pairwise comparisons appear as superscripts by each mean. Means within a column that share a letter are not significantly different ($p > 0.05$). [1] C = control; SB = Splenda for baking; EB = Equal for baking; TR = Truvia; SNL = Sweet'N Low; SB + S = Splenda for baking + sucrose; EB + S = Equal for baking + sucrose; TR + S = Truvia + sucrose; SNL + S = Sweet'N Low + sucrose.

Traditional sugar-snap cookies made with sucrose have a characteristic snap when broken rather than bending. This snap occurs because of the recrystallization of sucrose during and after baking [18]. Additionally, the inclusion of erythritol in Truvia aided in giving cookies from treatment TR a harder texture most similar to that of C. Erythritol tends to crystallize, creating a harder texture for the final product [23]. Alternative sweeteners disrupt the recrystallization of sucrose, making softer cookies that are more difficult to fracture [18].

3.6. Nutritional Profile

Cookies from treatment C had the highest calorie amount of 410 kCal per 100 g, whereas cookies from treatments TR, SNL, and TR + S had the least calories at 350 kCal per 100 g (Table 7). Calories mostly remained consistent between the alternative sweetener types, irrespective of whether sucrose was partially or totally replaced. Regardless of the classification as a starch or a sugar, digestible carbohydrates have an energy value of 4 kCal per gram.

Table 7. Summary of nutrition profile information calculated using Genesis.

Factor [1]	Calories (kCal/100 g)	Fat (g/100 g)	Protein (g/100 g)	Carbohydrates (g/100 g)	Added Sugar (g/100 g)
C	410	14	5	65	28
SB	370	17	6	47	0
EB	370	17	6	47	3
TR	350	17	6	56	0
SNL	350	17	6	47	4
SB + S	370	15	5	54	15
EB + S	370	15	5	54	16
TR + S	350	14	5	55	14
SNL + S	370	15	5	54	16

[1] C = control; SB = Splenda for baking; EB = Equal for baking; TR = Truvia; SNL = Sweet'N Low; SB + S = Splenda for baking + sucrose; EB + S = Equal for baking + sucrose; TR + S = Truvia + sucrose; SNL + S = Sweet'N Low + sucrose.

Added sugar was the lowest for the cookies with total sucrose replacement, ranging from 0 to 4 g per 100 g. Partial sucrose replacement resulted in cookies with 14–16 g per 100 g of sugar. Total sucrose replacement decreased the average added sugar by 94%, and partial sucrose replacement decreased the average added sugar by 46%. Added sugar was more affected by sucrose level than carbohydrates. Total sucrose replacement resulted in an average carbohydrate decrease of 24%. Partial sucrose replacement resulted in an average carbohydrate decrease of 17%. Carbohydrate amount was less affected by sucrose replacement than added sugar because many alternative sweeteners contain bulking agents that contain carbohydrates. The alternative sweeteners used in SB and EB contain maltodextrin. SB, EB, and SNL contain dextrose. All treatment cookies contain some dextrose from the cookie formulation. While maltodextrin and dextrose contain no sugar, these ingredients do contribute to carbohydrate content. Protein and fat content remained very similar between treatments.

The Dietary Guidelines for Americans, 2020–2025, recommend no more than 50 g of added sugar per day for an individual on a 2000 kCal diet [25]. The Reference Amount Customarily Consumed (RACC) for cookies is equal to one 30 g cookie [26]. Our control cookie has approximately 8.4 g of added sugar. Replacing all sucrose with Splenda, Equal, Truvia, or Sweet-N Low yields cookies with 0 g, 0.84 g, 0 g, and 1.12 g of added sugar, respectively. Partial sucrose replacement yields a range of 3.9 g–4.4 g of added sugar. Therefore, consuming one cookie with total or partial sucrose replacement a day would more easily allow individuals to remain within the given dietary guidelines with respect to added sugar.

3.7. Student Cookie Attribute Scoring

Cookies from treatment C had the overall highest rating for each category: appearance, texture, flavor, sweetness, and aftertaste (6.89, 6.32, 6.57, 6.43, and 6.07, respectively) (Table 8). Treatment TR was rated the lowest of all treatments for appearance (2.84) and texture (3.30). Treatment EB was rated the lowest for all treatments for flavor (3.79) and sweetness (2.62). C and TR + S had similar aftertastes ($p > 0.05$), and SNL was rated the lowest for aftertaste (3.02). No treatment was rated above a seven in any category on the hedonic scale. However, the AACC Method 10-50.05 is optimized for the physical and chemical analyses of cookies, not for flavor or sensory acceptability. A different formulation should be considered to yield greater ratings. However, trends in the attributes of cookies made with alternative sugars can still be analyzed using this formulation.

Table 8. Means and standard deviations for hedonic ratings (out of nine) of sensory attributes for each treatment.

Factor [1]	Mean Appearance Rating	Mean Texture Rating	Mean Flavor Rating	Mean Sweetness Rating	Mean Aftertaste Rating
C	6.89 ± 1.42^{a}	6.32 ± 1.60^{a}	6.57 ± 1.54^{a}	6.43 ± 1.68^{a}	6.07 ± 1.59^{a}
SB	$5.08 \pm 1.60^{c,d}$	$5.54 \pm 1.85^{a,b,c}$	$4.32 \pm 1.81^{b,c,d}$	$4.57 \pm 2.23^{c,d,e}$	$4.19 \pm 2.02^{b,c}$
EB	$4.95 \pm 1.66^{c,d}$	4.61 ± 1.78^{c}	3.79 ± 1.78^{d}	2.62 ± 1.59^{f}	$3.52 \pm 1.50^{c,d}$
TR	2.84 ± 1.51^{e}	3.30 ± 1.38^{d}	4.03 ± 1.95^{d}	$4.33 \pm 2.04^{d,e}$	$3.84 \pm 1.86^{b,c,d}$
SNL	4.35 ± 1.56^{d}	4.87 ± 2.04^{c}	3.86 ± 1.75^{d}	3.83 ± 1.92^{e}	3.02 ± 1.56^{d}
SB + S	$5.46 \pm 1.47^{b,c}$	$5.38 \pm 2.05^{a,b,c}$	$5.12 \pm 1.81^{b,c}$	$4.98 \pm 1.67^{c,d}$	4.75 ± 1.99^{b}
EB + S	$5.77 \pm 1.58^{b,c}$	$4.93 \pm 1.64^{b,c}$	$4.13 \pm 1.92^{c,d}$	3.95 ± 1.95^{e}	$4.36 \pm 1.94^{b,c}$
TR + S	5.41 ± 2.12^{c}	$5.92 \pm 1.71^{a,b}$	6.43 ± 1.53^{a}	$6.31 \pm 1.64^{a,b}$	6.05 ± 1.78^{a}
SNL + S	$6.33 \pm 1.45^{a,b}$	6.12 ± 1.57^{a}	5.16 ± 1.73^{b}	$5.39 \pm 1.57^{b,c}$	$4.43 \pm 2.16^{b,c}$

[a–f] Tukey pairwise comparisons appear as superscripts by each mean. Means within a column that share a letter are not significantly different ($p > 0.05$). [1] C = control; SB = Splenda for baking; EB = Equal for baking; TR = Truvia; SNL = Sweet'N Low; SB + S = Splenda for baking + sucrose; EB + S = Equal for baking + sucrose; TR + S = Truvia + sucrose; SNL + S = Sweet'N Low + sucrose.

The appearance of TR + S was not significantly different from that of SB + S and EB + S ($p > 0.05$) (Table 8). Treatment C was not significantly different from SB, SB + S, TR + S, or SNL + S in terms of texture. Only C and TR + S had significantly similar flavor, sweetness, and aftertaste ratings. Treatment EB had a significantly different sweetness rating from all other treatments. Equal for baking is made of maltodextrin, aspartame, and acesulfame potassium (Ace-K) ("Equal Original Granular", n.d.). Aspartame is not a heat-stable sweetener [27]. While maltodextrin (bulking agent) and Ace-K are heat-stable, they are not present in great enough amounts to impart sweetness to cookies baked with them. Maltodextrin has very low sweetness, so a greater amount is required to impart noticeable sweetness. Ace-K is only included in Equal for baking at a 1:4 ratio with aspartame ("Equal Original Granular", n.d.). This ratio indicates that Equal for baking does not impart an acceptable sweetness level for cookies.

In this experiment, treatments that included sugar in the formulation were rated higher on the hedonic scale than cookies prepared using only alternative sweeteners. Sugar has better functional properties in baked goods compared to alternative sweeteners, including rheology, dough viscosity, and Maillard browning [22]. These improved functions contribute to the better texture, mouthfeel, flavor, and color of the final product compared to cookies made with alternative sweeteners. Specifically, alternative sweeteners alone lack the bulking ability of sugar and require additional ingredients to form dough with favorable rheological properties and texture [22]. To compensate, alternative sweeteners that are used for baking are often combined with maltodextrin. Maltodextrin is a bulking agent that does not impart a great amount of sweetness. Additionally, alternative sweeteners have different flavor and sweetness profiles from sucrose. Splenda for baking is made of maltodextrin and sucralose; Equal for baking is made of maltodextrin, aspartame, and Ace-K; Truvia is derived from the plant Stevia rebaudiana; and Sweet'N Low is made of saccharin [27]. These sweeteners are significantly sweeter than sucrose alone but have potentially unpleasant or bitter aftertastes [27]. Overall, treatment TR + S was the best reduced-sugar alternative, yielding cookies most similar to C in all attributes scored except for appearance.

4. Conclusions

The results of this study show that sucrose plays a critical functional role in sugar-snap cookies. Depending on the level and type of the alternative sweeteners used, the replacement of sucrose produced cookies with a decreased spread, color change, hardness, and an increased fracturability. Reduced (50%)-sugar cookies had improved characteristics when alternative sweeteners were substituted for only part of the sucrose in the formulation. However, more research is needed to determine the optimal level and type/s of alternative sweeteners in cookie formulations. Additionally, further research could explore functional ingredients, such as bulking agents, fiber, and fat sources, to improve cookie spread, color, and texture attributes. Overall, our study found that TR + sucrose (50% replacement) and SB (100% replacement) were the closest to the control in terms of physiochemical characteristics.

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