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Evaluation of Artificial Sweeteners: Their Effects on Ice Cream Properties and Public Acceptance

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SENIOR THESIS APPROVAL

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Evaluation of Artificial Sweeteners: Their Effects on Ice Cream Properties and Public Acceptance

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Abstract

Background: The public is becoming more health conscious while sugar consumption, particularly frozen desserts, remains high. An evaluation of sugar alternatives that can maintain integrity of a product while providing fewer deleterious effects is necessary.

Objective: To assess the impacts of sugar alternatives on homemade vanilla ice cream while gathering information on a community's opinion of the effects.

Method: Ice cream samples made with sugar (control), Sweet'N Low®, Equal®, Splenda®, Stevia®, and monk fruit sweeteners were prepared for a taste test. A sensory evaluation was conducted on March 31, 2022 at Ouachita Baptist University. Microsoft Excel® was utilized to conduct descriptive statistics, frequency calculations, and one-way analysis of variance on the data gathered from 42 scorecards.

Results: Equal® yielded an ice cream sample that was most similar to the control sample regarding texture and flavor. Texture and flavor acceptability was most commonly reported for ice cream made with sugar and Equal®. Monk fruit sweeteners was quite tolerated regarding overall flavor.

Conclusion: Equal® was the best alternative for sugar in ice cream. To improve health, diet and behavior modifications should be combined for long-term benefits.

Introduction: Cookie Experiment

Free time emerged in the midst of the 2020 pandemic, compelling an inner sweet tooth to emerge and for this author to blossom as a baker, or rather, a professional chocolate chip cookie creator. Chocolate chip cookie is a simple, basic dessert and yet appealing to many souls. Curiosity sprouts into an investigation: what makes a recipe on the internet to be called the best, what causes it to be trendy, and why does the public love it so much? Thus began the research on what influences a cookie’s chewiness or crispiness, the differences in various types of cakes, or why a low-calorie ice cream still tastes like a regular ice cream. The outcomes from the directed study become a handy personal pocketbook and accidentally changed me into a walking encyclopedia on science behind desserts.

Review of Literature: Ice Cream Production

Basic ingredients in ice cream

Ice cream components must be examined to understand the way branded ice cream sweetened with sugar substitute still maintains the physical and sensory properties of normal ice cream. The structure of ice cream can be described as a colloid in which foam of air cells are trapped in a sugar solution composed of ice crystals, milk content and some type of sweetener.[1] The United States Food and Drug Administration (FDA) defines ice cream as a frozen dessert that needs to contain 10% milk fat, 20% milk solids, and 54% overrun.[2] Overrun is the volume change in ice cream mixture due to air incorporation during the churning process.

Air bubbles. Volume and softness are influenced by the number and size of air bubbles. Denser ice cream is achieved by having a lesser amount of air bubbles. A cheaper ice cream in the store is usually made by having higher overrun. Air is free, and it is the easiest way to increase volume with no cost.[2] Higher amount of air cells also result in slower melting rate since air bubbles act as an insulator, making it more difficult for heat to penetrate.

Ice crystals. Ice crystals form during the freezing process at the end of ice cream making. They provide firmness to the frozen dessert. The smaller the ice crystals, the smoother and creamier the ice cream. Larger ice crystals alter the perception of coldness in the mouth. The bigger size needs more heat that comes from the surrounding to melt the ice. The huge amount of heat taken out from the mouth causes the ice cream to feel colder.[2]

Milk. Milk and cream contribute to the stability of ice cream structure by providing fat and protein. Fat globules join together and form long pearl strings around the air bubble. Fat also thickens the mixture, and thus the mixture will have a slower meltdown and creamier texture. Fat also provides that indulgent flavor and mouthfeel as it coats the tongue. Meanwhile, milk proteins, along with lactose and minerals found in milk products, contribute to stabilizing the air bubbles trap.[2] Lactose also plays a part in adding extra sweetness.[1]

Sugar (sweeteners). Sugar is the highest component by volume in ice cream. The primary purpose is to sweeten the ice cream. Ice cream is served cold and has high fat content. The cold temperature numbs the taste buds while the fat coats the taste buds; both decrease taste functions. Consequently, sugar is added in a large amount to intensify the flavor.[1] Higher content of sugar also affects the freezing factor. When soluble ingredients are added to water, water's freezing temperature is immediately lowered. Solutes get in the way of water molecules trying to join together to form crystals. The higher the sugar content, the lower the freezing point. This will allow ice crystals to not be produced as much.[2] Ice cream's sweet taste can be achieved using sugar substitutes, however certain textural properties have to be adjusted using other ingredients. A study of the properties of ice cream made with Stevia® detected a lower melting rate, higher viscosity, and coarser textures.[3] The slow meltdown may be due to Stevia®'s larger molecular weight. A smaller molecular weight depresses the freezing point further as ingredients are measured by volume. The lower temperature difference between the ice cream mixture with sugar alternatives and the room temperature allows the ice cream to melt slower.[4] The hard texture is due to the lower amount of total solids; there is less interference that could prevent formation of large ice crystals. With these large crystals, the end texture will be grittier.[3]

Other ingredients. Some ice cream recipes ask for eggs and stabilizing agents. Eggs, especially egg yolks, contain lecithin, which is an emulsifier. Milk and cream are essentially homogenized. The milkfat is broken down into smaller particles so that the protein molecules can form a membrane around the tiny globules, preventing the fat globules from fusing with each other and thus suspending the fat throughout the solution. As a result, milk has a smooth texture.

Ice cream, however, needs the fat to partially coalesce so that the fat globules can form a network around air bubbles, stabilizing the structure. Emulsifiers will attach to the fat globules, displacing some of the milk proteins.[2] An emulsifier is composed of hydrophobic and hydrophilic parts, and it lowers the tension between fat and water more than protein does.[5] In other words, emulsifiers promote partial coalescence, which will provide a smoother ice cream.[2] Additionally, egg yolks provide extra fat content for a better flavor profile.[1] Stabilizer agents like egg whites and guar gum are water soluble polymers. The hydroxyl groups form hydrogen bonds with water molecules. Due to their large sizes however, the polymers do not dissolve in water and instead, thickens the ice cream mixture[4] and prevents the growth of ice crystals by reducing the amount of free water.[6] The higher viscosity allows reduction of air bubbles, because the mixture is harder to churn. Consequently, there is less formation of ice crystallization is formed. The end result then will have a softer texture.[7] The thick film also keeps the neighboring air bubbles away from each other, protecting ice cream quality despite longer storage time.[2]

Preparation methods

Preparing ice cream involves five steps: mixing, pre-chilling, aging, freezing/dynamic freezing, and hardening/static freezing. The first step requires heat as a mean of pasteurization, especially when eggs are used in the mixture. Heating up the mixture kills existing bacteria in raw eggs and other ingredients while also denaturing the proteins. Denatured proteins aid in the making of strong networks of membrane that stabilizes the trapped air bubbles. Usually, the mixture is heated up to 72°C (162°F) so that bacteria may be eradicated without too much denaturation, avoiding the eggy flavor that comes from denatured egg proteins.

Pre-chilling and aging occur at the same time before the dynamic freezing stage. The mixture is then cooled down in the fridge to prevent regrowth of bacteria in room temperature and to speed up the process of mixing in the ice cream machine. Reduced time in the ice cream machine is desirable for smoother texture since smaller crystals and low amount of air bubbles are formed.[2] Additionally, multiple chemical reactions occur when the mixture is stored in the fridge. As the fat solidifies, the proteins are displaced with emulsifiers more easily, and emulsifiers adsorb more strongly to the fat droplets' surfaces.[4] The importance of the aging process is exhibited during the dynamic and static freezing. The emulsion allows fat to coalesce in the next step as a stabilizer for air bubbles. When the fat droplets have crystallization, total coalescence, which gives an odd buttery flavor and texture, is prevented.[5] During the aging process, flavors develop deeper due to chemical reactions between molecules.[2] While the specific reactions are unknown, one hypothesis includes higher absorbance of liquid by the sugar molecules—a process that develops complex sweet flavor because sugar solution is easier to be tasted.[8]

The next step consists of freezing and churning. Three important developments happen during this process that affect the texture of the final product: rapid cooling, incorporation of air bubbles, and fat coalescence. Formation of ice crystals takes place where the mixture is in direct contact with the cold ice cream machine container. The blades then scrape the ice crystals from the sides of the container, incorporating them to cool the rest of the mixture.[2] Smaller ice crystals are desirable for smoother, rather than coarse, texture. Rotation speed and residence time in the machine are the biggest factors. High rotation speed increases heat output from the machine, which allows recrystallization. Recrystallization can be defined as any change in shape, size, and number of ice crystals. When recrystallization occurs, the small new ice crystals that were formed melt and join with each other, resulting in large ice crystals—this is the very reason ice cream forms ice crystals after being taken out from the freezer for the subsequent serving time.

Longer residence time is directly associated with fast speed. The faster the speed, the more the heat is produced, and therefore, the longer it takes for the mixture to cool down.[6] The churning typically stops at -5°C since that is the temperature where the mixture is so viscous that it becomes too difficult for further beating.[4]

The rotation movements also lead to addition of air bubbles into the mixture and coalescence of the fat globules. Constant motion breaks down the air bubbles and allows the fat to partially coalesce with each other randomly to form membranes around the air bubbles. Unlike the formation of ice crystals, high speed results in high shear stress—imposed force of rating blades—and produces smaller air bubbles that are desirable for creamier texture. Meanwhile, more time spent in the mixer reduces air cells size. Smaller air cells pack more tightly, leaving smaller spaces between the bubbles for ice crystals to grow, a favorable condition for producers and consumers alike. As mentioned before, the inclusion of one or more stabilizing agents increase viscosity, which is advantageous to the development of ice cream texture because the higher required force to beat the mixture will produce smaller air cells. Stabilizing the air bubbles comes from the clusters of fat globules that formed a network membrane with protein, nonfat milk solid particles, and emulsifiers.[9]

For some ice cream machines, manually freezing the container is required by continuous addition of ice and rock salt. A melting ice signals heat absorption from the ice cream mixture into the ice and thus more cold ice is necessary to continue the heat absorption. Ice melts at 0°C (32°F) by absorbing heat from the environment, yet this temperature is not low enough to cool the ice cream mixture.[1] The ice cream mixture holds sugar and other solid particles. Any substance dissolved in water weakens the lattice forces within solid crystals, resulting in less energy to break the intermolecular forces. As a result, the mixture freezes at a lower temperature.[4] Salt is thus added to lower the freezing point of water; the salt and ice mixture allows ice water mixture to reach equilibrium at a lower temperature.[10] The idea then is as ice transforms from solid to liquid, more ice crystals will be added to create a continuous low temperature that can cool the ice cream down. Since now the ice melts at a lower temperature, the whole machine is kept at a lower temperature, a proper temperature that allows ice cream to be frozen.

The last step is the hardening process that serves as a prevention for further ice crystallization or recrystallization. Ostwald ripening is a natural phenomenon in which smaller particles will dissolve and accumulate into larger cells to reach a more thermodynamically stable state. Smaller ice crystals will melt in the unfrozen portion of ice cream and others will aggregate as heat is removed from the unfrozen portion. Similar phenomenon occurs for the air bubbles as well. Storage in freezer cools the mixture down to -18°C (-0.4°F) to slow down the kinetics of this natural process. Fat content acts as mechanical obstruction to slow down the rate of the phenomenon.[10] Hardening time depends on overrun, ice crystal size, and fat destabilization content. High overrun percentage, large size of ice crystals, and more destabilizations increase hardening time.[11]

As can be seen, the production of ice cream requires a balanced art of air bubbles' and ice crystals' number and size. To have a smooth and creamy texture, the small air bubbles need to be evenly distributed, while the ice crystals need to be small. A new method using nitrogen liquid results in the creamiest mixture. According to Newton's law of cooling, the rate of cooling down a mixture depends on the difference between the temperature of the refrigerant and the mixture. The bigger the difference, the faster the rate. Nitrogen is liquid at -196°C (-320°F) while pre-chilled ice cream mixture is typically in the 0-4°C (32-40°F).[4] Liquid nitrogen provides a temperature far below freezing and evaporates as gas at room temperature. As such, when it is added to the ice cream mix, the ice cream freezes right away. Tiny ice crystals form and gas is added during the process, incorporating air bubbles instantly.[1]

Other Types of Frozen Desserts

Other than ice cream, there are many variants of the frozen dessert, depending on the milk fat content and additional incorporated ingredients. Ice cream is identified when the frozen dessert has 10-20% by weight of milk fat. Low fat ice cream has 2-7% fat but still has 8-15% milk solids nonfat (MSNF). Egg yolks may be detected up to 1.4%. Gelato becomes more prevalent and has a lower fat content (5-7%) because it has more milk than heavy cream.[12] No egg is added, yet it is creamier and denser due to a slower churning rate. Frozen custard has egg yolks and less air incorporation.[1] The FDA defined it to have more than 1.4% of egg yolk.[12] Sherbet and sorbet are similar in texture and flavor profile. Both are fruity because they use iced, sweetened fruit juice or puree as their bases. As a result, they have very low-fat content.[1] The difference lies in the presence of dairy products. Sorbet does not include any dairy components while sherbet must contain 2-5% of total milk solids.[12]

Review of Literature: Artificial Sweeteners and Ice Cream Market

Artificial Sweetener Properties

Sugar substitutes are more and more commonly used in cooking and baking. Also referred to as artificial sweeteners, low-calorie sweeteners, or non-nutritive sweeteners (NNS), they are synthesized sweetening agents that provide more than 200 times the sweetness of sucrose. While the other names refer to specific type of sugar substitute, they are interchangeable for simplicity's sake. NNS are not added in large quantity due to their high intensity sweetness, substantially providing zero calories in total when digested. Some other sugar alternatives do provide lower calories than sugar because of the bodies' inabilities to provide enzymes that can digest and absorb the ingested sweeteners properly, while others are not metabolized at all to give useful energy.[8] The public's concerns are geared towards the taste and structural effects of NNS to typical food and its consumption safety. Bitter aftertaste has been reported; however, the Academy of Nutrition and Dietetics demonstrated no adverse effects of NNS consumption to metabolism and overall health. Its safety is also addressed by the FDA. Before any NNS can be used by the food industry, FDA has tested it over and over with animal subjects and presents to the public regarding each sweetener's safe daily intake level (acceptable daily intake or ADI).[13] Below are some FDA-approved NNS that are commonly found in grocery stores.

Saccharin/Sweet'N Low®. Typically identified with the pink packets, Saccharin is commercially created from toluene, a benzene ring, and chlorosulfonic acid. The reaction yields an intensely sweet taste.[14] Saccharin is about 300 times sweeter and is heat stable.[15] A metallic aftertaste is commonly reported, and it has been demonstrated that the bitter taste receptors on the tongue are activated. One study identified activation of another nerve receptor responsible for metallic taste sensation. These mechanisms account for the bitter and metallic taste of

Saccharin.[14] It is also the one NNS that caused the cancer controversy in the 1970s. However, in 2000, the many human studies have concluded that the NNS was not a potential carcinogen.[16] ADI for Saccharin is 5 mg/kg body weight (BW) or about 45 packets per day.[17,18] It provides slightly less than 4 kilocalories (kcal) per gram.[19]

Aspartame/Nutrasweet®/Equal®. Aspartame is made up of two amino acids, aspartic acid and phenylalanine. Since it can be metabolized, it does provide calories in high doses. One gram of aspartame contains 4 kcal;[19] however, it is 200 times sweeter. Consequently, consumers only use a fraction of a gram, and thus, the total calories do not matter as much. Aspartame becomes a concern for those who are diagnosed with phenylketonuria, a genetic disorder that causes phenylalanine to build up to harmful levels in the body. Therefore, its blue packets must have a warning message regarding its phenylalanine content.[10] One of the downsides is this NNS is not heat stable.[16] ADI for Aspartame is 50 mg/kg BW or about 75 packets per day.[17,18]

Acesulfame Potassium (Acesulfame-K)/Sweet One®. Acesulfame Potassium is derived from salt combined with acetoacetic acid.[10] Similar bitter taste receptors stimulation to Saccharin is revealed, which contributes to the off taste of Acesulfame-K.[14] Due to its stability in heat, it is typically used in frozen desserts and baked goods. It is about 200 times sweeter.[16] The ADI is 15 mg/kg BW or about 23 packets per day.[17,18]

Sucralose/Splenda®. The only NNS made from sucrose is sucralose, in which three hydroxyl groups are substituted with chlorines.[15] It is 600x sweeter, heat stable, and typically sold with a blend containing bulking agents.[10] ADI for Sucralose is 5 mg/kg BW or about 23 packets per day.[17,18]

Neotame/Newtame®. A more recently approved NNS is neotame, the sweetest artificial sweetener as it can be 7000-13,000 times sweeter than sugar.[10] The ADI is 0.10 mg/kg BW or about 23 packets per day.[17,18] It also has nutritive values.[19]

Steviol glycosides/Stevia®. One of the natural NNS is Stevia®, which is extracted from *Stevia rebaudiana* Bertoni leaves, native to South America. They are 300x sweeter and usually combined with sugar alcohol. Stevia® usually has a bitter aftertaste but is heat-resistant, perfect for baking.[8] ADI for Stevia® is 4 mg/kg BW or about 9 packets per day.[18]

Tagatose. Tagatose is a fructose isomer. Its only concern is for those who have fructose metabolism issues. Its most common use is for sugar alternative in ice cream.[15]

Luo Han Guo/Monk Fruit. Another natural source of NNS is luo han guo, a small green fruit from Asia.[15] Mogrosides, the compound responsible for sweetness in monk fruits, are abundant in the fruit extract. The extract is 100 to 250 times sweeter than table sugar.[16] The ADI is unknown.[18]

Sugar alcohol. Sugar alcohol is another sugar alternative commonly used in the health-conscious ice cream brands, such as Halo Top. Structurally, it is similar to sucrose but contains alcohol molecules. It does not belong to the NNS category because the body can still digest and absorb it, but in a slower and poor manner.[8] As such, sugar alcohol provides less than 4 calories per gram but may have a laxative effect or cause other gastrointestinal symptoms in large quantity. The alcohol functional group carries water-holding properties.[18] Additionally, incomplete absorption of these molecules prompts the gut microbiome to digest the leftover sugar alcohols, leading to fermentation. The products of fermentation are gases that bring about digestive disturbances.[20] It is not as sweet as sucrose, providing only up to 90% sweetness.

Concerns arise due to the structural effect it has to final food product but can be compensated when paired with other NNS and bulking agents.[13]

Erythritol is quite prevalent in the world of frozen desserts. It is stable in heat and extreme pH environments without giving a distinct aftertaste. It is also the most well-tolerated sugar alcohol when compared to the other types. After its rapid absorption in the small intestine, the excess is excreted in urine.[20]

Health Effects of Artificial Sweeteners

While companies advertised the sugar alternatives in a positive light, the public perception of artificial sweeteners is negative. Due to the emerging research linking NNS with health risk in animals, many became apprehensive with sweeteners affecting obesity, cancer, and other health problems despite FDA approval on their safety.[21] Lower acceptance of NNS is attributed to the “artificial-ness” of NNS, while approval of natural NNS, such as Stevia®, is found to be higher.[22] A 2021 survey reported that food and beverages sweetened with Stevia® or monk fruit sweetener were more likely to be consumed than those with other low-calorie sweeteners.[23] Lack of knowledge in regulations by FDA contribute to the negative perception of artificial sweeteners as well.[22] In addition to safety, skepticism on NNS health benefits remained high.[21]

Many health concerns about NNS are regarding its impact on gut health and whether its efficacy in weight reduction is valid and reliable. The quantity and composition of gut microbiota affects physiological functions such as immunity, gastrointestinal motility, vitamin production, and metabolism of nutrients and drugs. Several studies in rats detected a shift of microbiome that negatively alters glucose metabolism with high consumption of NNSs. However, studies with human subjects and other clinical trials concluded insufficient evidence to support beneficial or adverse effects of NNS on gut microbiome and metabolism function.[19]

Moreover, while causality of artificial sweeteners and weight gain could be ruled out, behavioral variables must be considered. One suggestion is that if sweet taste—from NNS—is psychologically associated with low caloric density, overeating may occur. The risk factors for obesity and diabetes epidemic are more associated with attitudes on food, rather than the actual food consumption.[22]

The other side of the dilemma argues for the health benefits of low calorie and low sugar ice cream, along with its compatibility with diabetes. About 10.5% of the population (34.2 million) was diagnosed with diabetes.[24] The three percent increase of diabetes diagnosis in the past two decades became a large health concern in the public health field. Obesity has also increased at the same time as weight gain behaviors became more prevalent. The most recent Centers for Disease Control and Prevention data showed that US obesity prevalence was 42.4%.[25] Pellegrini et al. observed that high sweet consumptions were significantly associated with adverse weight and body mass index (BMI) changes.[26] The pandemic in 2020 exacerbated unhealthy behaviors: low activity levels, increased snacking behaviors, and high processed food consumptions. Diabetes and obesity have adverse effects on overall health and comorbidity, such as heart disease and other metabolic disorders. Poor health status then has domino effects on mental health, stress, and other life aspects.[27-29]

While the intake of added sugar has decreased since 2000, it is still higher than the dietary guidelines created by the government.[13] The guidelines recommended that intake of added sugar to not exceed 10% of the calorie intake, which is different for each individual. Using the standard 2000 kcal diet, 10% is 200 kcal or about 12 teaspoons of added sugar.[30] The most recent National Health and Nutrition Examination Survey found that on average, people in the US consumed added sugar that totaled in 12.7% of their recommended calorie intake. On the other hand, the American Diabetes Association stated that NNS caters to people with diabetes well, since it can reduce overall calorie content, play a role in overall healthful diet, and most importantly, does not affect glycemic response.[31] Additionally, people with higher BMI tend to perceive high health benefits of NNS than normal BMI. The marketing strategies developed suggest that education for consumers might help to withstand misleading information. A simple and easily accessible evidence-based messages could be effective in bringing neutral opinions regarding NNS.[22]

The current trend exhibits expanded awareness of health status. As disposable income and organizations grew, health consciousness also grew. People become more engaged in searching for accurate health information and in undertaking health actions. Forbes observed consumer trends of enthusiasm in sharing knowledge on food quality and balanced diet.[32] The innovations in food science and technology played a factor for food choice motivation as well as government encouragements. The push for healthier goals and restrictions on unhealthy food by the federal government contribute to the trend.[33,34] Simmons National Consumer Survey reported that 291.09 million Americans or about 88% of United States (US) population consumed frozen dessert in 2020.[35] According to International Dairy Foods Association, Americans reported vanilla as their top favorite ice cream flavor.[38] The trend to find healthier and cleaner food products led to the development of ice cream that is low calorie, low sugar, plant-based, high protein, or any other produce that provide health benefits yet still delicious. This was reflected in an almost 50% rise in low sugar ice cream market.[33,36-39] Halo Top brand dominated the healthy ice cream sale, gaining popularity in 2018.[39-41] The brand contained only 280-370 calories for pint-size tub through the use of sugar substitutes. However, it received a significant backlash with the reason that consuming a pint of ice cream encourages people to eat more than the recommended serving, distorting the mindset and lifestyle into overriding natural hunger and fullness cues along with reinforcing dependence on processed foods.[37,40,41]

Thesis Statement

The increasing health concerns have led to variations of ice cream to purchase. While many are marketed as “healthy”, the actual health effects need to be assessed. At the same time, foods’ chemical components and physical properties appeal to the senses and motivate people to eat and enjoy it. Investigating differences on properties of ice cream made with different sweeteners and consumers’ preferences of the alternative ice cream will provide the food industry and researchers with beneficial information regarding ice cream developments—whether the low-calorie, low-sugar ice cream worth the sensory and financial sacrifices. The purpose of the research then is to examine the community’s opinion on vanilla ice cream made with different sweeteners using quantitative descriptive analysis sensory assessment.

Methods

Ice Cream Mix Preparation

Six ice cream mixes were prepared. Each was based off a recipe titled *How to Make Vanilla Ice Cream* by allrecipes.com, which only asked for granulated sugar, heavy whipping cream, whole milk and vanilla extract, yielding four servings. The control ice cream mix followed the recipe exactly: milk, cream, sugar, and salt were heated and continuously stirred until all the solid particles were dissolved. The mixture then was transferred to a container with a lid. Vanilla extract was added before the ice cream was cooled in the fridge overnight (more than 12 hours). Every other mixture substituted the granulated sugar with saccharine/Sweet'N Low®, aspartame/Equal®, sucralose/Splenda®, Stevia®, or monk fruit sweetener. Saccharin, aspartame, and sucralose were in packets. The equivalent of ¾ cup of sugar was 16 packets. Stevia® and monk fruit sweetener were 1:1 ratio substitute to sugar, and therefore the measurement of ¾ cup was kept the same. Three mixtures were manufactured at a time. The same saucepans to heat up the three mixtures were washed and dried before being used again for the last three mixtures. The recipe for each mixture is shown in Table 1. After the overnight refrigeration at 4°C, the mixes were churned with Hamilton Beach® 4 Quart Collapsible Bucket Ice Cream and Custard Maker. After 25-30 minutes of churning, the mixture was then returned to its container and stored in the freezer for the final freezing process. The whole preparation started two nights before the testing day. All ice cream samples for the evaluation were prepared in Nutrition and Dietetics Food Science Lab at Ouachita Baptist University (OBU).

Table 1. Ice Cream Formula Used for Sensory Evaluation of Ice Cream Made with Sugar Alternatives.

Ingredients	**Control (Sugar)**	**Sample with Sweet'N Low®**	**Sample with Equal®**	**Sample with Splenda®**	**Sample with Stevia®**	**Sample with Monk Fruit Sweetener**
Sweetening Agent	¾ c.	16 packets	16 packets	16 packets	¾ c.	¾ c.
Heavy Whipping Cream	1 c.					
Milk	2 ¼ c.					
Vanilla Extract	2 tsp.					
Salt	A pinch					
Directions	Stir sugar, salt, cream, and milk into a saucepan over medium-low heat until sugar has dissolved. Do not boil. Transfer cream mixture to a container. Stir in vanilla extract and chill for at least 2 hours (overnight is best). Pour the cold ice cream mix into an ice cream maker and follow the manufacturer's directions.					

Subjective Evaluation

Sensory evaluation is a careful analysis of the appearance, aroma, flavor, and texture of a food product, usually performed by trained professionals.[10] On Thursday, March 31, 2022, a sensory evaluation was carried out by a group of random panelists. Each ice cream mixture was roughly portioned out into 45 clear cups. The samples were coded with a 3-digit random number and assessed using a rating scale of 1 to 5 for appearance, texture, flavor, and acceptability. Three attributes were assigned to each score (Table 2). Iciness characteristic referred to the grittiness of the overall ice cream sample when bitten or chewed in the mouth. Meanwhile, softness, or the lack thereof, referred to the ease in scooping the ice cream with a spoon. Ice cream samples with Stevia® was represented by the code 611, Equal® by 454, control/sugar by 097, Splenda® by 276, Sweet'N Low® by 323, and monk fruit sweetener by 951. The scorecard and taste test were approved by the OBU Institutional Review Board.

Table 2. Scorecard Handed to Panelists for the Sensory Evaluation of Ice Cream Made with Sugar Alternatives.

Characteristics	**Sample Number**					
	611	**454**	**097**	**276**	**323**	**951**
Color 1 = Stark white 3 = Creamy white 5 = Yellow-white						
Iciness 1 = Smooth, Creamy 3 = Icy 5 = Too icy/gritty						

Table 2. ***cont.***

<u>Softness</u> 1 = Mushy 3 = Soft 5 = Hard						
<u>Texture Acceptability</u> 1 = Not acceptable 3 = Acceptable 5 = Very acceptable						
<u>Sweetness</u> 1 = Not sweet 3 = Pleasantly sweet 5 = Too sweet						
<u>Aftertaste</u> 1 = No aftertaste 3 = Slight aftertaste 5 = Distinct aftertaste						
<u>Flavor Acceptability</u> 1 = Not acceptable 3 = Acceptable 5 = Very acceptable						

Participants were recruited randomly through an invitation email sent to all students. Scorecards and informed consent were handed out. Informed consents were collected before the test was conducted. Briefings on the proper method for sampling ice cream as well as explanation of subjective evaluation testing were communicated before the participants were presented with the six samples. They were allowed to sample in a sequence of their choosing.

Statistical Analysis

A total of 43 scorecards were collected. One scorecard was not included in the statistical analysis due to incomplete scoring. The data from the scorecards were then inputted to Microsoft Excel® for further analysis. Descriptive statistics as well as one-way analyses of variance (ANOVA) and Tukey's honestly significant difference (HSD) test were conducted. Results were considered significant for $p<0.05$. Nutrient analysis was assessed using MyFitnessPal® online application. All the ingredients were added, and the total value of a nutrient was then divided into four for the recipe suggested for four servings.

Results

One-way ANOVA of F (5,246) reached significance, $p<0.001$, on all characteristics evaluated except for color (Table 3). Each of the sample has a rather creamy off-white color as indicated by the mean scores: ice cream with sugar was 3.05, with Stevia® 2.98, with monk fruit 2.79, with Sweet'N Low® 2.74, with Splenda® 2.64, and with Equal® 2.52.

The sensory evaluation displayed that the ice cream made with Stevia® and Splenda® led the way for highest scores in iciness (3.60 and 3.48 respectively) and softness (3.33 and 3.31 respectively). The higher scores meant quite icy and hard textures of these samples. Additionally, Tukey's HSD test indicated significant difference ($p<0.05$) between every pairing with control samples for iciness. For softness attributes, Tukey's HSD test only reached significant for pairings between the control sample and Stevia® or Splenda®. Despite so, texture acceptability was only positively indicated for the samples made with regular sugar and Equal® as demonstrated by Tukey's HSD test, which showed significant differences on the pairings between sugar and every other NNS except Equal®. Additionally, about 76% of participants rated the texture as acceptable or better for Equal® and 90% of participants rated similarly for the control sample. The others had less than ¾ of the participants noting them as acceptable, with monk fruit sweetener having the worst score since almost half of the participants reported not acceptable for texture acceptability.

Table 3. Statistical Analysis of Vanilla Ice Cream Taste Test Scorecards: Frequency Table and One-Way ANOVA Results.

Characteristics	Score	Frequency (%)						One-Way ANOVA
		Stevia®	Equal®	Sugar	Splenda®	Sweet'N Low®	Monk Fruit	F (5, 246)
Color	1 - Stark White	12	26	10	24	24	24	1.378
	2	2	5	2	2	5	2	
	3 - Creamy Off-white	74	64	74	67	57	60	
	4	0	0	2	0	2	0	
	5 - Yellow White	12	5	12	7	12	14	
	Mean (± SD)	2.98 (±1.00)	2.52 (± 1.04)	3.05 (±0.96)	2.64 (±1.08)	2.74 (±1.21)	2.79 (±1.24)	
Iciness	1 – Smooth, Creamy	7	43	95	10	31	60	21.257*
	2	0	2	0	0	0	2	
	3 - Icy	55	40	5	57	45	14	
	4	2	2	0	0	2	0	
	5 - Too Icy	36	12	0	33	21	24	
	Mean (± SD)	3.59 (±1.19)	2.38 (±1.38)	1.10 (±0.43)	3.48 (±1.23)	2.83 (±1.46)	2.26 (±1.70)	
Softness	1 - Mushy	29	45	55	17	29	48	8.144*
	2	0	2	5	5	0	0	
	3 - Soft	24	50	40	43	55	29	
	4	5	0	0	2	5	0	
	5 - Hard	43	2	0	33	12	24	
	Mean (± SD)	3.33 (±1.69)	2.12 (±1.09)	1.86 (±0.98)	3.31 (±1.42)	2.71 (±1.27)	2.52 (±1.64)	

*$p<0.05$

Table 3. *cont.*

Texture Acceptability	1 - Not Acceptable	29	21	10	21	24	45	7.094*
	2	2	2	0	5	5	0	
	3 - Acceptable	67	50	38	57	57	40	
	4	0	2	2	0	0	0	
	5 - Very Acceptable	2	24	50	17	14	14	
	Mean (± SD)	2.45 (±0.99)	3.05 (±1.38)	3.83 (±1.32)	2.86 (±1.26)	2.76 (±1.25)	2.38 (±1.43)	
Sweetness	1 - Not Sweet	57	17	0	24	67	17	11.242*
	2	2	0	0	5	0	0	
	3 - Pleasing	31	79	93	64	24	52	
	4	2	2	2	2	0	5	
	5 - Too Sweet	7	2	5	5	10	26	
	Mean (± SD)	2 (±1.29)	2.74 (±0.86)	3.12 (±0.45)	2.60 (±1.04)	1.86 (±1.34)	3.24 (±1.32)	
Aftertaste	1 - None	12	43	48	24	12	40	13.738*
	2	0	5	5	2	0	2	
	3 - Slight	33	36	43	45	26	43	
	4	2	0	0	2	0	0	
	5 - Distinct	52	17	5	26	62	14	
	Mean (± SD)	3.83 (±1.40)	2.42 (±1.47)	2.10 (±1.16)	3.05 (±1.45)	4 (±1.41)	2.45 (±1.40)	

*$p<0.05$

Table 3. *cont.*

Flavor Acceptability	1 - Not Acceptable	60	12	5	31	71	36	22.803*
	2	2	0	2	5	0	0	
	3 - Acceptable	38	40	31	45	21	38	
	4	0	2	5	0	0	2	
	5 - Very Acceptable	0	45	57	19	7	24	
	Mean (± SD)	1.79 (±0.98)	3.69 (±1.37)	4.07 (±1.20)	2.71 (±1.42)	1.71 (±1.24)	2.79 (±1.55)	

*$p<0.05$

In regard to flavor, ice cream made with sugar led the way for the most common report of pleasantly sweet flavor. It was then followed by Equal® with 79% of participants indicated pleasantly sweet, 64% for Splenda®, and 52% for monk fruit sweeteners. More than half of the participants indicated that ice cream made with Stevia® or Sweet'N Low® were not sweet (57% and 67% respectively). This particular finding was further confirmed by the Tukey's HSD test, which displayed significant difference between sugar and Stevia® regarding sweetness, as well as between sugar and Sweet'N Low®.

Aftertaste was most prominent for Stevia® and Sweet'N Low® as testified with 52% of participants and 62% marking distinct aftertaste, respectively. Splenda® also showed a significant difference from the control sample (Tukey's HSD, $p<0.05$), with 26% reported distinct aftertaste, 45% reported slight aftertaste, and 24% reported no aftertaste.

Ice cream made with regular sugar had a significantly higher average score than Stevia®, Splenda®, Sweet'N Low®, and monk fruit sweetener for flavor acceptability (Tukey's HSD, $p<0.05$). Looking at the scorecard data, ice cream with Equal® (88%), sugar (93%), monk fruit sweetener (64%), and Splenda® (64%) had at least half of the participants agreeing that it was acceptable or very acceptable. The control received the most reports on very acceptable with 57% said so and the highest mean score valuing at 4.07, followed by Equal® at 3.69. See Figure 1 for summary of all mean scores compared.

The ice cream made with NNS contained less carbohydrate content and therefore, lower calorie content. The difference per serving between the control sample and the rest of the samples was 144 kcal or 36 g of carbohydrates.

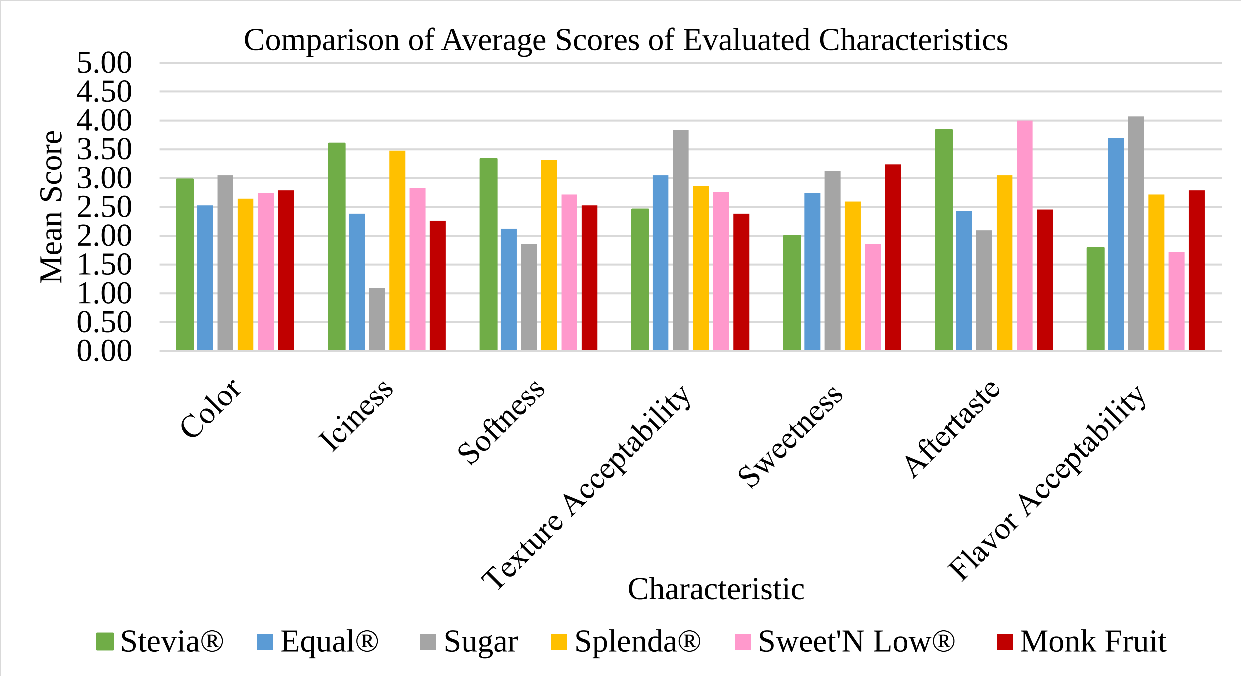

Figure 1. The Mean Scores of Evaluated Characteristics of Vanilla Ice Cream Made with Different Sugar Alternatives.

Discussion

When looking at the ice creams' appearances, no significant differences were detected, indicating that the artificial sweeteners did not impact the color of the end product. In contrast, texture and flavor were affected, more so by certain NNS. Sweet'N Low® produced a rather icy, hard ice cream with a harsh aftertaste and displeasing flavor. Even though participants mostly reported it as not sweet, it could be assumed that it was not a lack of sugary flavor, but an unpleasant off-flavor. Saccharin had been known to have a metallic and/or bitter aftertaste.[14] Just like Sweet'N Low®, Stevia® had a distasteful flavor and aftertaste, which was expected as bitter taste was generally known for Stevia®.[8] Splenda® had similar reports like these two but was more tolerated.

The other sweeteners also generated a rather icy texture. Splenda® and Stevia® also had higher average scores, 3.33 and 3.31 respectively, on the softness attribute, denoting a hard texture rather than soft. While softness, or the lack thereof, could be associated with the freezing process before the evaluation started, the icy texture was correlated with the properties of NNS. Since NNS required less amount to be equal in sweetness, the ice cream mixture contained lower number of total solids.[3] Stevia® and monk fruit sweetener were added at the same volume but due to the different molecular structures, they both weighed less than granulated sugar at the same volume measurement. The other three NNS were definitely less than ¾ of a cup to reach similar sweetness level, totaling at 21 g. Consequently, large ice formation was not impeded enough by the solids existing in the mixture.[3] Texture-wise, the quality of the control samples were superior to the samples made with NNSs. Ice cream with Equal®, however, was the most well-tolerated. The other NNS, except for monk fruit sweetener, were tolerated too as could be seen by the fact that at least two out of three participants would accept the texture quality.

Concerning flavor and the effects of NNS on it, Equal® seemed to be doing the best in yielding the most similar result to granulated sugar as 79% of participants indicated pleasantly sweet and 88% marked it as acceptable, very acceptable, or in between the two. One of the reasons that Equal® was less intense in its flavor profile was its instability with heat. A disadvantage of using aspartame as sugar alternative is it is not heat stable, losing sweetness with higher temperature.[16] However, this feature became beneficial as the ice cream produced was not too sweet nor was it displeasing overall.

Monk fruit sweetener had the most ambiguous results. For the most part, this sample went down the middle road with many of the attributes evaluated. While many participants scored it as the worst, evidenced by its average score on texture acceptability (2.38), at least half of the participants still tolerated its texture. Not many complained about its flavor. In fact, it had the best score for sweetness (3.24) after the samples with granulated sugar (3.12) and had minimal aftertaste like Equal® and sugar. When asked for the rankings concerning flavor acceptability, monk fruit sweetener comes third.

All NNS did provide less calories and carbohydrate content, which would be ideal for those diagnosed with diabetes mellitus (DM).[31] While 144 calories may not be much of a reduction, 36 g of carbohydrates is a considerable amount for those mindful of carbohydrate counting. The switch to using sugar alternatives may help reduce the psychological burden and fatigue from dealing with long-term DM. To increase efficiency in reducing caloric intake, NNS might help if behavior modifications were also included in the lifestyle changes. The health diseases that are rising currently are more associated with behaviors than the actual food consumption.[22] Any small cut in calorie intake will affect the long-term health status.

This study on artificial sweeteners has drawbacks as taste test, no matter how formal, is subjective. Due to time constraints, a more objective evaluation on the effects of NNS on ice cream properties, such as measurements on meltdown rate and overrun differences, was not conducted. Additionally, cooking methods and the nonsystematic approach to churning and freezing of the ice cream mixtures could have influenced the textures of the yielded ice creams—some ice creams were already melting while the others were still frozen. Another limitation was the taste test's environment was not thoroughly controlled or systematical, which could have influenced the scoring of the ice creams' characteristics. Yet, the taste test was useful to determine which of the NNS was a suitable alternative for homemade ice cream and whether there were differences in public's acceptability among the different sweeteners. The information will be valuable for making informed decisions regarding NNS and for further evaluation on cost-effectiveness of NNS. Future research to assess the impacts objectively or to dive deeper into one of the artificial sweeteners are recommended for confirming or disproving the subjective evaluation of ice cream.

Conclusion

To address the rising health concerns about sugar consumption, alternative sweeteners are good options in reducing overall sugar intake without taking out the psychological burden of eradicating a food group altogether. However, each type of sweetener has its own pros and cons. Ice cream made with Equal® provides the best resemblance to ice cream made with regular sugar and the public seemed to approve the alternative for its overall texture and flavor. Meanwhile, Sweet’N Low® and Stevia® are not recommended as replacement for sugar when preparing a homemade ice cream. With any nutrition-related goals, NNS is a beneficial first step in improving health status if not overconsumed. Long-term efficacy, however, depends more on dietary behavior alterations rather than food consumptions.

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