









A multidimensional sensory approach to natural sweeteners and prebiotic fiber for replacing added sugar in yogurt

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Abstract

Strategies to reduce sugar consumption are still necessary, given that, in populous countries such as Brazil, the consumption of added sugar remains high. Excessive sucrose consumption is associated with the increasing prevalence of diseases, prompting the food industry and public health sectors to explore strategies such as the use of sweeteners and other ingredients to reduce or replace sucrose. This study aimed to determine the equivalence and sweetness potency of natural sucrose substitutes (fructooligosaccharides, stevia, xylitol, and isomaltulose) in yogurts, analyze their temporal sweetness behavior, characterize their sensory profile, and assess consumer acceptance. The equivalent concentrations for sucrose sweetness (5.10%) were stevia (0.0263%), fructooligosaccharides (23.88%), xylitol (6.10%), and isomaltulose (18.20%). Time-intensity analysis revealed that the samples exhibited a temporal sweetness profile very similar to sucrose, with fructooligosaccharides and isomaltulose showing the highest sweetness intensities. In the check-all-that-apply test, fructooligosaccharides and isomaltulose samples were primarily characterized by texture attributes and were positioned opposite to stevia and xylitol samples. Consumers preferred yogurts added with isomaltulose, fructooligosaccharides, and sucrose. Therefore, replacing sucrose with a prebiotic fiber and natural sweeteners in yogurts is a viable strategy, considering sensory characteristics and consumer acceptability.

Keywords: magnitude test; time-intensity; check-all-that-apply; consumer acceptance.

Practical Application: Different natural sweeteners and prebiotic fibers have shown promise as sugar substitutes in yogurt.

1 INTRODUCTION

Sugar has long been a significant and often hidden source of calories in the diet (Oliveira et al., 2016). In 2022, global consumption totaled 176.318 million tons, representing a growth of 4.2% (7.045 million tons) compared to the previous year (International Sugar Organization [ISO], 2025b). The global average per capita consumption in 2021 was 21.4 kg (ISO, 2025a; Medeiros et al., 2024). The main sugar-consuming markets include India, the European Union, China, the United States, Brazil, Indonesia, Russia, Pakistan, Mexico, and Egypt (ISO, 2025a, 2025b). This excessive consumption is associated with an increased prevalence of chronic non-communicable diseases (NCDs) such as obesity, diabetes, and metabolic syndrome (Oliveira et al., 2016), responsible for 75% of all deaths globally (World Health Organization [WHO], 2025), which reinforces the urgency for preventive dietary strategies.

As a result, consumer behavior has shifted toward healthier eating patterns, with a growing preference for natural and functional foods, perceived as better options for health (Azevedo et al., 2017; McCain et al., 2018; Pereira et al., 2021). This health-focused trend has influenced governments and

industries to adopt strategies to reduce sugar content in processed foods. Public policies targeting sugar reduction and industrial reformulations reflect a broader movement to improve the nutritional and technological quality of foods while maintaining the sensory characteristics desired by consumers. One of the most effective strategies to reduce sugar intake without radically altering dietary habits is the partial or total replacement of alternative sweeteners. This approach is being adopted worldwide (Chadha et al., 2022; Cheng et al., 2024; Wan et al., 2021).

Among the various options, non-nutritive sweeteners derived from natural sources, such as steviol glycosides (stevia), have received growing attention due to their high sweetness (200 to 300 times greater than sucrose) and their safety for human consumption (Andrade et al., 2024; Wan et al., 2021; Yang et al., 2022). Other promising alternatives include sugar alcohols (sorbitol, xylitol, and isomalt), low-calorie sugars (isomaltulose), and oligosaccharides (fructooligosaccharides—FOS, and inulin). These sweeteners are absorbed more slowly in the gastrointestinal tract, resulting in lower glycemic and insulin responses, making them especially suitable for diabetic

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consumers (Carocho et al., 2017; Edwards et al., 2016; Guggisberg et al., 2011). These sweeteners also differ in their sensory characteristics. The xylitol has a sweetness intensity comparable to that of sucrose, with fewer calories and no residual bitter taste (Akesowan, 2015; Grembecka, 2015). Isomaltulose, marketed as palatinose, offers a mild sweetness, around 50% of that of sucrose (Mu et al., 2014). FOS are prebiotic fibers that support the growth of beneficial intestinal bacteria, are more soluble than sucrose, and provide fewer calories (Dominguez et al., 2014; Mabel et al., 2008).

Despite their advantages, replacing sucrose in food products presents sensory profile challenges. The sensory performance of sweeteners is influenced by factors such as the intensity and duration of sweetness, the aftertaste, and the food matrix. These factors can vary depending on the concentration of the sweetener, the product's temperature, or its fat content (Chadha et al., 2022; McCain et al., 2018). Therefore, given the importance of the food matrix in sensory performance, incorporating these sweeteners into yogurt requires thorough sensory assessment, making comprehensive characterization essential (Pereira et al., 2021).

In this context, this study stands out for adopting a multidimensional approach to sweetness—combining descriptive, temporal, and affective sensory analyses—applied to different classes of sweeteners, both natural and with functional claims, in a widely consumed dairy matrix like yogurt. This approach contributes to the development of healthier products without compromising sensory acceptance and provides the food industry with tools to design formulations with functional and technological appeal. Therefore, this study aims to investigate the potential of xylitol, isomaltulose, FOS, and steviol glycoside as sucrose substitutes in yogurt. Specifically, it focuses on their sensory profiles, both descriptive and temporal, and consumer acceptance. In addition, the study evaluates the equivalence and sweetness potency of these substitutes compared to sucrose.

1.1 Relevance of the work

This study stands out for adopting a multidimensional approach to sweetness—integrating descriptive, temporal, and affective analyses—applied to the evaluation of different classes of sweeteners, both natural and with functional claims, in a widely consumed matrix such as yogurt. The approach contributes to the development of healthier dairy products without compromising sensory acceptance and provides support to the industry in the formulation of foods with functional and technological appeal.

2 MATERIAL AND METHODS

Samples

Samples of natural yogurt without the addition of sucrose or sweeteners were purchased from the Verde Campo dairy industry (Lavras-MG, Brazil). The other ingredients used were fructooligosaccharide (SENSUS-Fructose[®] OFP), xylitol (Nutrify[®]), isomaltulose (Vitafor[®]), and steviol glycoside

(75% Rebaudioside A + 25% Stevioside) (Tasteva[®], Tate & Lyle, London, United Kingdom).

The composition of yogurt in a portion of 100 g consisted of 6.6 g of carbohydrates (3.3 g of glucose, 3.3 g of galactose, and 0 g of lactose), 5.7 g of proteins (60% proteins and 40% casein), 0 g of total fat, 0 g of saturated fats, 0 g of trans fats, 0 g of dietary fiber, 58 mg of sodium, and 110 mg of calcium.

Sensory analysis

We performed the sensory test sessions at the Sensory Analysis Laboratory of the Department of Food Science of the Federal University of Lavras (UFLA) in individual booths. The ethical issues were approved by the Ethics Committee in Human Research at UFLA (CAAE: 64259616.9.0000.5148). Participants were daily consumers of yogurt, male and female, ranging in age from 18 to 60 years. The yogurts were distributed to the assessors at a cooling temperature of 4°C.

2.2.1 Assessor selection

In total, 30 subjects were recruited, and the selection was made based on basic taste recognition tests (International Organization for Standardization, 2012) and triangular tests with yogurt containing two different concentrations of aspartame with a significant difference, obtained through the paired comparison test, at the 1% level of significance (Souza et al., 2011).

Thereafter, we applied Wald's sequential analysis (Amerine et al., 1965) to verify the candidates' ability to discriminate samples (Meilgaard et al., 1999). We consider the values of $p = .30$ (maximum acceptable disability), $p_1 = .70$ (acceptable minimum ability), and for risks $\alpha = 0.10$ (probability of accepting a candidate without sensory acuity) and $\beta = 0.10$ (probability of rejecting a candidate with sensory acuity). Based on the defined parameters, we used two equations to construct the Wald analysis graph, which comprises three areas: acceptance, doubt, and rejection. The assessors were selected or rejected according to the number of correct tests analyzed in the chart. We selected 15 assessors for the test to determine the sweetness equivalent concentrations of FOS and the different sweeteners (xylitol, stevia, and isomaltulose) and time-intensity test.

2.2.2 Magnitude test

2.2.2.1 Training for analysis with magnitude scale

The selected assessors were trained to familiarize themselves with the magnitude scale methodology and explain the correct use of the scale (Souza et al., 2011). In the training, we used three samples of sweetened yogurts in the concentrations of 3.20, 5.10, and 8.16% of sucrose. The assessors were asked to estimate the intensity of sweetness compared to the reference (5.10% sucrose), performed on three replicates.

2.2.2.2 Determination of equivalence and sweetness potency in yogurts

The central concentration of sucrose used was 5.10%, according to Ribeiro et al. (2020). The central concentrations of the

sucrose substitutes were based on the relative sweetness power according to the manufacturer’s information and confirmed or readjusted by pre-tests. To calculate the other concentrations, we used a multiplication factor of 1.6, according to Souza et al. (2011), presented in Table 1. We performed the tests in three sessions, for each of the substitutes and for sucrose.

The selected and trained assessors received a reference sample R (yogurt with an ideal addition of sucrose—5.10%), with intensity designated as an arbitrary sweetness value of 100, followed by five samples of yogurt (20 mL) with different concentrations of sucrose and its substitutes (Table 1) coded in balanced order (Macfie et al., 1989). The assessors were asked to estimate the sweetness intensities of the coded samples relative to the R reference. For example, if the sample had twice the sweetness of the reference, it should receive the value 200, if it presented half the sweetness, 50, and so on.

2.2.3 Time-intensity

2.2.3.1 Training and selection

The 15 selected assessors underwent sweetness intensity training to participate in the time-intensity (TI) analysis. In the three training sessions, the assessors were instructed and familiarized with the SensoMaker data software (Pinheiro et al., 2013), and the initial waiting time and the total test time were defined as 2 and 30 seconds, respectively. In the training, the assessors received three codified and randomized samples of yogurts (20 mL) with sucrose concentrations of 4.25, 5.10 (ideal sweetness), and 6.12%.

2.2.3.2 Time-intensity final test

In this step, the assessors evaluated five samples of yogurt (20 mL) randomly monadic in three replicates. The samples were the ideal concentration of 5.10% of sucrose and the equivalent sweetness concentrations of FOS and natural sweeteners. The selected and trained assessors registered the perceived intensity of sweet taste over the established time.

We obtained the data for the test by using the program SensoMaker, version 1.91, UFLA, Lavras, Brazil (Pinheiro et al., 2013). The parameters of the IT curve were: I_{max} (maximum intensity), TI_{max} (maximum intensity time), plateau (maximum intensity duration time), area (area under the curve), T_d (time corresponding to the point where the maximum intensity begins to decline), and total T (total time of stimulus duration).

The 10-points scale was used for the analysis, with 0 referring to no perception and 10 referring to an extreme perception of the evaluated taste.

2.2.4 Check-all-that-apply and acceptance

The check-all-that-apply (CATA) method was performed by 106 randomly recruited yogurt consumers, who evaluated the five coded samples (20 mL) in a balanced and monadic order (Varela & Ares, 2012). One of the samples corresponds to the ideal sucrose concentration (5.10%), and the others correspond to the equivalent concentrations of FOS and natural sweeteners in relation to sucrose.

The survey of the most relevant characteristics of yogurts was defined through a focus group (Lawless & Heymann, 2010) with the participation of 20 consumers of yogurt. The list of attributes consisted of 19 attributes plus the “other” option, in which the consumer was free to express any other perceived attributes that were not included in the list. The attributes were sweet taste, sour taste, astringency (characteristic of green banana), natural yogurt flavor, fermented milk flavor, refreshing flavor, metallic, citrus flavor, oily aftertaste (greasy mouth sensation), sweet aftertaste (sweetness that remains in the mouth), bitter taste, flavorless, creamy, full-bodied, aerated, watery, velvety, viscous, sandy (presence of crystals), and others.

In order to perform the CATA analysis, the consumers were instructed to read the attributes present on the sheet before starting the analysis. Then, we request that they try the samples, and after that, they should check the attributes that, in their judgment, were appropriate to describe each sample. There was no fixed number of attributes to be checked, so the assessors could check one or more, according to their opinion in relation to the sample (Varela & Ares, 2012).

Finally, consumers were instructed to rate how much they liked or disliked the samples for overall liking by using a 9 cm non-structured hedonic scale in which the left end was anchored with the term “extremely disliked”, the center corresponded to “indifferent to the sample”, and the right with “extremely liked”. Posteriorly, the markings made by the consumers were converted to numerical values. The numerical values of the samples were obtained by measuring (using a ruler) the marks made by the consumers, considering the left extremity corresponding to 0 cm, the center to 4.5 cm, and the right extremity corresponding to 9 cm (Stone & Sidel, 1985).

Table 1. Concentrations of the sucrose samples and the substitutes thereof used to determine the equivalence of sweetness to the ideal of 5.10% sucrose in yogurt.

Samples	Concentrations (%)				
	2.00	3.20	5.10	8.16	13.06
Sucrose	2.00	3.20	5.10	8.16	13.06
Stevia	0.009	0.014	0.022	0.035	0.056
FOS	8.00	12.75	20.40	32.64	52.22
Xylitol	2.00	3.20	5.10	8.16	13.06
Isomaltulose	6.38	10.20	16.32	26.11	41.77

FOS: fructooligosaccharides.

2.2.5 Statistics analysis

2.2.5.1 Magnitude scale

In order to proceed with the data analysis, we converted the estimated sweetness magnitude values of the sucrose and its substitutes to geometric means, and these values were adjusted to a logarithmic scale. A first-order regression model was then obtained, describing the relationship between concentration and sensory response for each ingredient. Based on the log–log transformation, this relationship followed a power function of the form $S = aC^n$, where S is the sensation perceived, C is the concentration of the stimulus, a corresponds to the anti-logarithm of the intercept value, and n represents the angular coefficient of the fitted linear equation (Moskowitz, 1970).

Initially, we used the sucrose function to calculate the equivalent concentration of the substitutes. Instead of C (sucrose concentration), the value of 5.10%, corresponding to the ideal sweetness of sucrose in the yogurt, was attributed. In this way, it was possible to calculate the parameter S , which is the perceived sweetness sensation in natural yogurt made with sucrose. The value of S for sucrose was then replaced in the sweetener and FOS equations, and thus we determined the ideal concentration of FOS and of each sweetener in the same equivalence to yogurt with 5.10% sucrose (Moskowitz, 1970; Souza et al., 2011).

The sweetness potency of the substitutes was defined by the number of times that the compound is sweeter than sucrose, based on its sweetness equivalent to sucrose. In other words, the ratio between the concentration of sucrose used in natural yogurt (5.1%) and the equivalent concentration of the substitutes in the same equivalence to the yogurt with sucrose addition (Souza et al., 2011).

2.2.5.2 Time-intensity data analysis

In the final selection of the TI, the results of the training for the maximum intensity parameter (I_{\max}) were evaluated by using the analysis of variance (ANOVA) for each assessor and for the evaluated stimulus, selecting the assessors according to the capacity of discrimination ($p < .30$) and repeatability ($p > .05$).

The final test data collected for each curve parameter (I_{\max} , TI_{\max} , $plateau$, $area$, T_d , T_{total}) were evaluated by using the ANOVA ($p \leq .05$) and by the Tukey test for comparison of sample means. When a significant difference was observed in the interaction between sample and assessor ($p \leq .05$), the software PanelCheck was used to identify the assessors who were not in consensus with the others (Tomic et al., 2007). Thus, participants who disagreed were identified and excluded from the analysis, and the ANOVA was again performed. The software SensoMaker version 1.91 (Pinheiro et al., 2013) was used to do the data analysis.

The TI curves of the five samples were plotted with the parameters collected during the analysis, using the software Sigma Plot version 11.0. We used the means of all the assessors and all the replications for each one of the samples during the time of analysis (Souza et al., 2013).

We used principal component analysis (PCA) to analyze the mean of the parameters of the TI curves and to evaluate the differences and similarities among the samples based on their summarized parameters. The analyses were performed on SensoMaker version 1.91 (Pinheiro et al., 2013).

2.2.5.3 Analysis of check-all-that-apply data and acceptance testing

In the CATA data analysis, the citation frequency of each attribute was determined by counting the number of times consumers marked each attribute for each sample, called the contingency matrix.

We apply Cochran's Q test in order to verify significant differences among samples for each attribute using the statistical software R (R Core Team, 2019). We apply the correspondence analysis (CA) on the matrix containing the citation frequency of the attributes for which significant differences were detected by the Cochran's Q test (Meyners & Castura, 2014; Meyners et al., 2013). We used the package SensoMineR (Le & Husson, 2008) from the software R (R Core Team, 2019).

To verify if there was a difference among the samples, we evaluated the results of the sensory attribute (global impression) obtained from the acceptance test by using ANOVA at a significance level of 5% ($p \leq .05$), followed by the Tukey test for comparison of means (Souza et al., 2013).

3 RESULTS AND DISCUSSION

3.1 Equivalence and power of sweetness

A linear regression of the points for each substitute and the sucrose was obtained, and the linear equations were determined for each according to Figure 1.

According to the positioning of the curves (Figure 1), it was possible to identify the relative sweetness power of the sucrose substitutes. It can be seen that the proximity of the sucrose and xylitol curves indicates that a very similar amount of xylitol was required compared to sucrose to produce the same sweetness perception. The distance of the curves of FOS and isomaltulose in relation to the sucrose demonstrated that a greater quantity of these substitutes was necessary to reach the perception of sweetness of 5.10% conferred by sucrose. Stevia was noted for requiring a minimum quantity, justified by its high potency in relation to other substitutes, because it is a natural high-intensity sweetener (Gasmalla et al., 2014; Guggisberg et al., 2011).

In Table 2, we present the power functions, the linear correlation coefficients, the equivalent concentrations of each substitute required to provide the same sweetness as 5.1% sucrose, and the sweetness potency of each substitute.

From Table 2 and Figure 1, it can be seen that FOS and isomaltulose had low potencies compared to sucrose, i.e., in yogurt, it is necessary to add approximately five times as much FOS and four times more isomaltulose in relation to sucrose for the same sweet sensation. The stevia presented a sweetness potency of approximately 200 times greater than sucrose, and xylitol presented a sweetness potency close to sucrose.

Considering the technological features and the health benefits, replacing sucrose with xylitol becomes an interesting strategy. Technologically, xylitol has favorable features for its application in products, such as high solubility and high osmotic pressure; it acts as a preservative contributing to the microbial stability of several products, does not participate in reactions of non-enzymatic browning (Maillard's reaction and caramelization), lower viscosity in solution compared to sucrose, stable at high temperatures and changes in pH, and non-cariogenic (Akesowan, 2015; Cai et al., 2017; Carocho et al., 2017; Mushtaq et al., 2010).

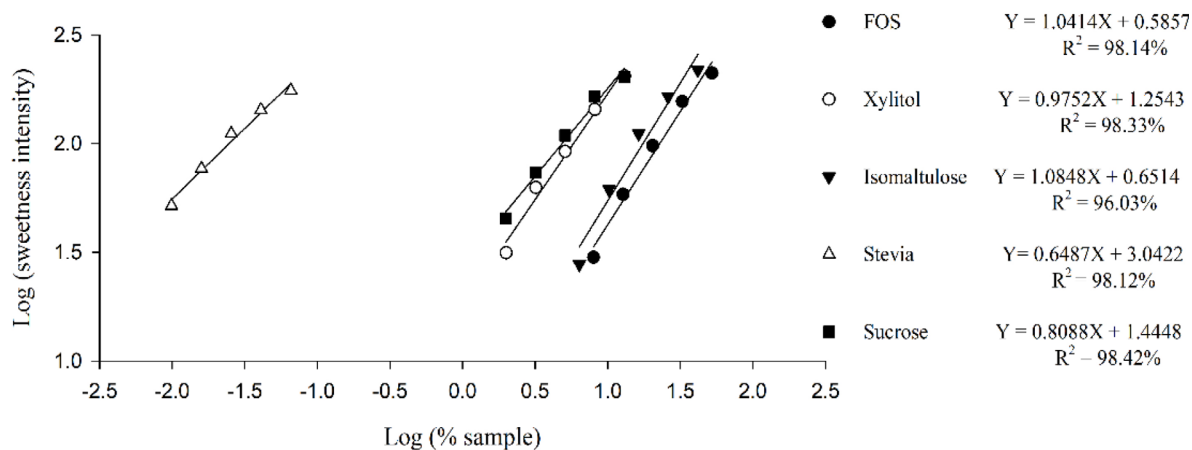
In relation to physiological properties and beneficial health effects, xylitol is notable for being absorbed slowly in the gastrointestinal tract, having a low glycemic response, and not interfering with the level of insulin because it is metabolized by the organism by independent routes of insulin; therefore, it is suitable for application in products that serve the diabetic public (Carocho et al., 2017; Edwards et al., 2016; Rasouli-Pirouzian et al., 2017).

In this study, isomaltulose presented a sweetness potency lower than that reported in the literature. According to Grembecka (2015), the relative sweetness of isomaltulose varies from 45 to 65% compared to sucrose, since it depends on the concentration, temperature, food matrix, and characteristics of the product in which it is used. In relation to FOS, the literature reports low sweetness power (Dominguez et al., 2014; Yun, 1996), which corroborates the result obtained in the present study, as well as for the xylitol that is mentioned as having

the same perception of sucrose sweetness (Akesowan, 2015; Grembecka, 2015).

Considering the low sweetness potency of the FOS, the amount required for the total sucrose substitution exceeds the maximum value set by the legislation. According to Food and Drug Administration (2016), the maximum allowed daily intake of FOS is 20 g; that is, in 100 g of yogurt, the required amount of FOS to obtain the equivalence of sucrose sweetness was 23.88 g, which exceeds the recommended daily consumption, and it is not feasible to replace total sucrose with the prebiotic FOS. However, a viable alternative would be to associate it with other natural sweeteners to achieve desirable sweetness, since, as it is prebiotic, its daily consumption brings benefits to human health, such as modulation of the intestinal microbiota (Valcheva & Dileman, 2016), increased bioavailability and absorption of minerals (Aryana & McGrew, 2007; Pimentel et al., 2015), reduction in the risk of colon cancer, beneficial stimulus to the immune system, and changes in lipid metabolism with a decrease in the synthesis of triglycerides and very-low-density lipoproteins (VLDL) (Aryana & McGrew, 2007; Saad et al., 2011).

Regarding isomaltulose, the sweetness equivalent to sucrose was 18.20%, and the total sucrose substitution is feasible, since the World Health Organization does not specify the acceptable daily intake (ADI), so it does not establish the maximum limit that could be used in the product, it is because consumption of isomaltulose is considered safe and has no toxicological effects. In addition, the gastrointestinal tolerance of isomaltulose is similar to sucrose, and no gastrointestinal discomfort is observed



FOS: fructooligosaccharides.

Figure 1. Linearized power function for yogurt sweetened with sucrose, fructooligosaccharide, and natural sweeteners (stevia, xylitol, and isomaltulose).

Table 2. Power function, linear coefficient of determination (R^2), concentration, and potency of natural sweeteners and fructooligosaccharides equivalent to the 5.10% concentration of sucrose in yogurt.

Sample	Power function	R^2 (%)	Concentration (%)	Potency
Sucrose	$S = 27.85(5.1)^{0.8088}$	98.42	5.10	---
Stevia	$S = 1101.50C^{0.6487}$	98.12	0.0263	193.91
FOS	$S = 3.85C^{1.0414}$	98.14	23.88	21.35
Xylitol	$S = 17.96C^{0.9752}$	98.33	6.10	83.60
Isomaltulose	$S = 4.48C^{1.0848}$	96.03	18.20	28.02

FOS: fructooligosaccharides; S: sensation perceived.

even at high doses, because it is totally metabolized (Aidoo et al., 2013, Sentko & Willibald-Ettle, 2012).

The health benefits of replacing sucrose with isomaltulose have been of interest; although the disaccharide is completely hydrolyzed to glucose and fructose and absorbed, this metabolism occurs gradually, avoiding glycemic and insulinemic peaks. Therefore, the low glycemic index is advantageous for diabetic individuals as well as for the general public. In addition, ingestion has been associated with a greater contribution of fat utilization to total energy expenditure, mainly in physically active individuals, and is a non-cariogenic nutritional sweetener (Aidoo et al., 2013; Guggisberg et al., 2011; Henry et al., 2017; Kawaguti & Sato, 2010).

3.2 Time-intensity

Table 3 shows the mean of the I_{max} parameters and area for each sample in relation to the sweet taste with the sensory panel composed of 13 assessors, in which a non-significant sample*assessor interaction was guaranteed ($p \geq .05$).

Samples of yogurts sweetened with sucrose, FOS, and natural sweeteners did not present significant differences ($p \leq .05$) for $TI_{5\%}$, $TD_{5\%}$, $TI_{90\%}$, $TD_{90\%}$, and plateau, being statistically different only for I_{max} and area parameters (Table 3). It can be verified that the samples with isomaltulose and FOS presented higher I_{max} , being similar to each other and both statistically different from sucrose. Samples with stevia and xylitol were the same as sucrose. Regarding the area, a statistical difference was observed only between the stevia and xylitol samples. However, all samples, including FOS and isomaltulose, do not differ from sucrose relative to the area under the TI curve (Table 3).

Figure 2A shows the time-intensity curves of the five yogurts sweetened with sucrose, different natural sweeteners, and the prebiotic fiber FOS in concentrations equivalent to 5.10% of sucrose, obtained from the means of the assessors.

According to Figure 2A, the sweetness profile of the xylitol sample compared to sucrose showed similarity for the maximum intensity and total duration of the stimulus. Isomaltulose and FOS presented similar profiles among themselves, with higher I_{max} when compared to sucrose. It is observed that for stevia, only the perception of maximum intensity took a longer time to occur.

Although maximum intensity was not expected to show significant difference among the samples, because the equivalent

Table 3. Mean values of the sensory panel for the parameters of the time-intensity curve for sweet taste.

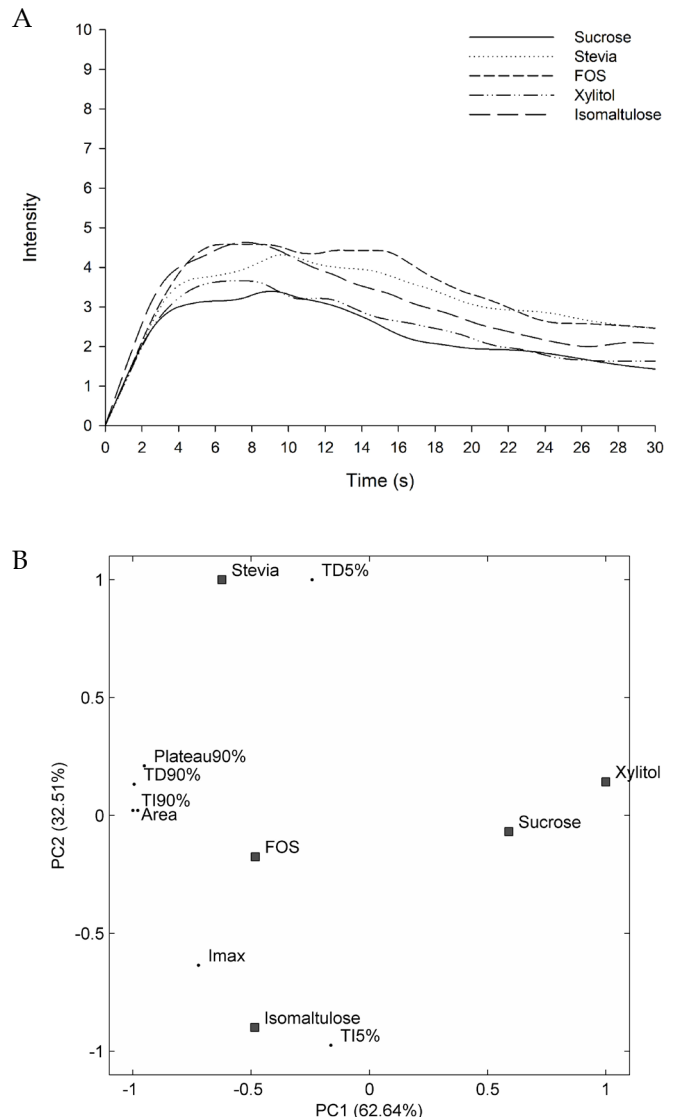
Sample	I_{max}	Area
Sucrose	5.57 ^a	81.43 ^{ab}
Stevia	5.92 ^{ab}	102.81 ^b
FOS	6.60 ^{bc}	94.00 ^{ab}
Xylitol	5.71 ^a	76.28 ^a
Isomaltulose	6.82 ^c	101.18 ^{ab}

Means followed by the same letter in the same column did not differ statistically from each other ($p \leq .05$) according to the Tukey test.

FOS: fructooligosaccharides; I_{max} : maximum intensity; Area: area below the curve.

concentrations of all substitutes relative to sucrose were analyzed, we understand that the texture influenced the temporal sweetness perception of samples added with FOS and isomaltulose, which were perceived as more full-bodied and creamy compared to the others, a fact confirmed by CATA descriptive analysis (Figure 3).

A similar result has been observed in the studies of Cadena and Bolini (2011) and Alcaire et al. (2017), which state that several factors such as viscosity, temperature, chemical status of the saliva itself, presence of flavorings and starch in the solution, among others, can influence the perception of sweet taste, since in the studies with traditional and light vanilla ice



I_{max} : maximum intensity; $TI_{5\%}$: time when the intensity is 5% of the I_{max} in the increasing part of the curve; $TD_{5\%}$: time when the intensity is 5% of the I_{max} in the decreasing part of the curve; $TI_{90\%}$: time when the intensity is 90% of the I_{max} in the increasing part of the curve; $TD_{90\%}$: time when the intensity is 90% of the I_{max} in the decreasing part of the curve; Plateau 90%: time in which the intensity interval is $\geq 90 I_{max}$; Area: area below the curve; FOS: fructooligosaccharides.

Figure 2. (A) Time-intensity profile of yogurt samples sweetened with sucrose and different substitutes and (B) principal component analysis of the parameters of the time-intensity curves.

cream and with dairy dessert, the perception of the sweet stimulus increased with the increase of the lipid content and with greater concentrations of vanilla aroma and starch, respectively. The authors assume that an increase in viscosity and/or changes in salivation may improve taste perception by modulating the processing of flavor and aroma signals.

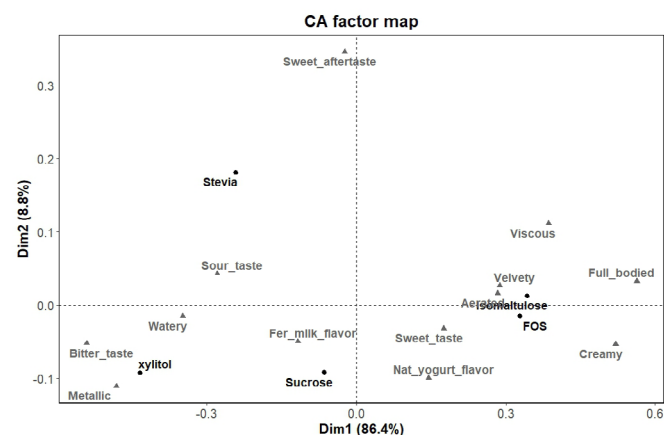
The PCA explained 95.15% of the data variability, where the variance of the first principal component corresponded to 62.64% and the second represented 32.51% (Figure 2B). All the parameters of the TI analysis were highlighted in the discrimination of the samples with stevia, FOS, and isomaltulose, which was not observed for sucrose and xylitol (Figure 2B). We verified that the parameters I_{max} and $TI_{5\%}$ were able to discriminate the samples with FOS and isomaltulose and emphasized the similarity of the two samples in relation to the others. The $TD_{5\%}$ parameter had a greater contribution to discriminating the sweetened yogurt with stevia, indicating that the residual perception of sweetness takes a longer time until it is no longer perceived.

3.3 Check-all-that-apply analysis and acceptance test

The assessors did not report any additional attributes in the sensory data sheet for the description of the samples. The frequency with which consumers used 13 out of 19 attributes listed in CATA showed significant differences ($p \leq .05$) between the samples in the Cochran's Q test. Therefore, these attributes contributed significantly to the discrimination of the samples. For only six attributes, there was no significant difference: astringency, refreshing flavor, citrus flavor, residual oil, flavorless, and sandy.

A CATA correspondence graph was generated with the 13 significant attributes to discriminate the samples (Figure 3). The results of the CA show that the first and second dimensions represent approximately 95.16% of the variance of the data, with 86.35 and 8.81%, respectively (Figure 3).

From the sensorial map (Figure 3), we can see that the yogurts with FOS and isomaltulose were characterized mainly by the attributes of texture, such as viscous, full-body, creamy,



CA: correspondence analysis.

Figure 3. Representation of the terms and yogurt samples in the first and second dimensions of the correspondence analysis performed in the contingency table check-all-that-apply.

aerated, velvety, and those attributes that contributed to the distance of the sample with sucrose in ratio to be characterized by a watery texture. In relation to the flavor attributes, the yogurts sweetened with sucrose, FOS, and isomaltulose were described as having a sweet taste and the taste of natural yogurt.

The yogurts sweetened with stevia and xylitol were described by the attributes of fermented milk flavor, sour, bitter, metallic taste, and stevia was also highlighted by a sweet aftertaste, and for texture both were evidenced to be waterier (Figure 3). The literature reports the perception of bitter taste by the use of stevia in different products such as chocolates (Azevedo et al., 2017), pitanga nectar (Freitas et al., 2016), mango (Cadena et al., 2013), passion fruit juice (Rocha & Bolini, 2015), and jelly fruits (Souza et al., 2013). In addition, it has been reported that the sweetening properties of steviol glycosides differ among them due to their structures, and a bitterness aftertaste is conferred by stevioside, whereas rebaudioside does not confer such an expressive intensity of residual taste, with better taste quality and sweetness (Cadena et al., 2013; Lemus-Mondaca et al., 2012). Once the stevia used in the study has in its composition the presence of rebaudioside and also stevioside, the perception of bitterness may have been perceived more sharply as a function of the presence of this last compound.

The isomaltulose and xylitol were mentioned in the literature as responsible for giving texture to products, since they are mass and texturing agents (Carocho et al., 2017; Grembecka, 2015), which corroborates the results obtained in the present study, in which the isomaltulose-sweetened yogurt was characterized by texture attributes, such as full body and creamy. However, xylitol-sweetened yogurt was characterized by a watery texture, which may be justified because its potency is very similar to sucrose, with the amount of solids added being lower compared to isomaltulose.

The results of the acceptance test are shown in Table 4. Samples of yogurt with sucrose, FOS, and natural sweeteners presented significant differences ($p \leq .05$) in the hedonic scores in relation to the overall impression.

It can be observed that consumers preferred the samples sweetened with isomaltulose, FOS, and sucrose, respectively, indicating greater acceptance regarding overall impression (Table 4). Isomaltulose presented the highest mean score (5.84), differing significantly from sucrose. Also, according to the mean comparison test (Table 4), although FOS (5.58) showed a higher

Table 4. Mean values and standard deviations of acceptance of the five yogurts.

Sweetener	Mean and SD
Sucrose	5.01 ± 1.96 ^{bc}
Stevia	4.09 ± 2.03 ^a
FOS	5.58 ± 1.95 ^{cd}
Xylitol	4.58 ± 1.84 ^{ab}
Isomaltulose	5.84 ± 1.97 ^d

Means followed by the same letter in the same column do not differ statistically from each other ($p \leq .05$) according to the Tukey test.

FOS: fructooligosaccharides; SD: standard deviation.

mean score than sucrose (5.01), this difference was not statistically significant.

Considering the unstructured scale used in the study, in which scores lower than 4.5 corresponded to how much the consumers disliked the sample, the stevia-sweetened yogurt was the least accepted, presenting a mean score of 4.09 (Table 4), which can be justified by the sweet and bitter aftertaste confirmed in CATA (Figure 3). The second yogurt, less preferred by consumers, was the one sweetened with xylitol, with an average score of 4.58, this score being located very close to the scale center (4,5), which corresponded to how much the consumers were indifferent to the samples, explained by the same attributes that characterize the stevia in the CATA analysis (Figure 3).

The texture and flavor attributes reported in the CATA analysis seem to have contributed to the better acceptance of yogurts sweetened with FOS and isomaltulose (Figure 3). The attributes of sweetness and texture are of extreme importance in the perception of dairy products such as yogurts, dairy desserts, and chocolate milks for the acceptance of the consumers, being that sugar is not only an ingredient that confers sweetness but also positively influences the thickness, creaminess, and moisture retention (Oliveira et al., 2015).

Morell et al. (2015) concluded in their study that the attributes of sweetness and creaminess, associated with density and thickness, were important in yogurt considered ideal by consumers for a product with great satiety appeal.

The acceptance of a product by consumers is mainly driven by flavor and texture, and it is important to consider that both are directly related, since the perception of one can lead to changes in the sensorial perception of the other (Jeltema et al., 2016), and especially for dairy products, the creaminess is an important feature in product acceptance (Guggisberg et al., 2011) and taste perception.

Therefore, FOS and isomaltulose are presented as potential alternatives for the substitution of sucrose in yogurts, provided that they comply with the legislation, contributing to the reduction of daily intake of the same and reflecting positively on the balance of food planning, quality of life of the population, and the technological characteristics of the product, such as texture and flavor.

4 CONCLUSIONS

To obtain sweetness equivalent to the ideal of 5.10% sucrose in yogurts, we find out that stevia, xylitol, isomaltulose, and FOS should be added at concentrations of 0.0263, 6.10, 18.20, and 23.88%, respectively. The substitutes presented a temporal profile of similar sweetness; however, FOS and isomaltulose had higher maximum intensities. Yogurts with FOS and isomaltulose were characterized as viscous, consistent, creamy, aerated, and velvety, while sucrose conferred a watery texture, and for flavor, the three samples were described as having a sweet taste and natural yogurt flavor. The attributes of texture and flavor made these samples the most preferred by consumers. The samples with stevia and xylitol showed fermented milk flavor, sour and bitter taste, metallic and sweet aftertaste, and watery attributes.

These characteristics contributed to making them the least preferred samples.

Therefore, replacing sucrose with prebiotic and natural sweeteners in yogurts is a well-accepted and promising consumer strategy, since the reduction in sucrose consumption provides additional health and quality of life benefits, a growing consumer desire. In addition, this research provides scientific information on the sensory aspects of FOS and natural sweeteners for future work on the development of mixtures as a strategy for reducing or replacing sucrose in products and with increased functionality through prebiotic action.

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