Research Article

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Application of multiple-intake temporal check all that apply: a case study of strawberry yoghurt formulated with alternative sweeteners

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Abstract

BACKGROUND: It is crucial to reduce the high sugar content of fruit yoghurts in response to the excessive weight gain epidemic. The use of alternative sweeteners in yoghurts is often associated with the negative sensory attributes that can have an impact on yoghurt liking. The main objective of this research was to investigate the effect of alternative sweeteners and strawberry puree addition on the temporal sensory profile of yoghurt using multiple-intake temporal check all that apply (TCATA). A novel approach to the statical analysis of the temporal sensory data was employed by using aligned rank transformation–analysis of variance to investigate the differences between sensory attributes within different products and within different intakes.

RESULTS: Results showed that the attributes sweet and fruity decreased when the concentration of fruit puree was increased at low concentration of sucrose. Interestingly, when the concentration of fruit puree was increased, fruitiness increased and mouthcoating decreased at low concentration of stevia. With successive intakes, the attributes sweet, sour, creamy and fruity significantly decreased in yoghurts sweetened with sucrose, xylitol and stevia. Yoghurts containing low concentrations of sucrose or xylitol and fruit puree were liked the most. However, stevia-sweetened yoghurts varying in sweetener and puree concentration were not significantly different in liking. In order to investigate the consumer acceptance of yoghurts, a novel approach was used – that is, utilizing TCATA temporal data to investigate temporal drivers of liking for each yoghurt type.

CONCLUSION: The use of multiple statistical analysis to analyse temporal data suggested that both sweetener and puree concentration need to be considered when developing products using alternative sweeteners.

Supporting information may be found in the online version of this article.

Keywords: ART–ANOVA; fruit puree; xylitol; stevia; yoghurt; temporal drivers of liking

INTRODUCTION

The fruit yoghurt market is projected to grow at a CAGR (compound annual growth rate) of 7.0% between 2020 and 2025.[1] A combination of yoghurt and fruit is advantageous as it can have synergistic effects on health by providing probiotics, prebiotics, protein, fatty acids, and a mixture of vitamins and minerals. Additionally, the use of different fruit flavours not only improves the flavour characteristics of yoghurt, but also increases consumer options, which helps in marketing of yoghurt and retaining consumer interest with ever-changing food habits. However, the high sugar content in fruit yoghurt is of great concern. Coyle *et al.*[2] found that sugar in flavoured yoghurts ($n = 2285$) in supermarkets across three countries (Australia, South Africa and England) ranged from 0.1 to 22.6 g 100 g^{-1} with a mean of 11.5 g 100 g^{-1}, of which 42% was free sugar. In response to public health concerns about the excessive weight gain epidemic, removing or replacing sugars from dairy foods and beverages has become even more crucial than before. However, removing sugar from food impacts not only its perceived sweetness but also the overall flavour perception, functionality and texture of food.[3,4]

The use of alternative sweeteners is the most common technique for sugar reduction in the dairy industry. However, it is important to highlight that during the replacement of sucrose with alternative sweeteners other attributes apart from sweet such as sour, astringent, bitter, metallic and off-flavour should also

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be considered.[5] This is because different alternative sweeteners vary in their intensity of sweet taste, tooth-coating ability and aftertaste profile.[6] These disparities in sensory profile with the use of alternative sweeteners can impact overall liking of the product. Past research reported that yoghurts formulated solely with sucrose, sucralose or xylitol had significantly higher scores for overall impression in terms of acceptance test (evaluated using a 9-point hedonic scale) than yoghurts formulated with stevia or erythritol.[7] In another study, authors found that the acceptance of yoghurts increased with increase in sucrose or xylitol concentration.[8] However, acceptance decreased with increase in stevia concentration due to bitter taste and residual flavour. In a more recent study, protein beverages formulated with stevia or monk fruit scored were not well liked due bitter, metallic and astringent taste.[9]

As flavour perception is a dynamic experience,[10] it is important to evaluate changes in the different sensory characteristics throughout consumption for successful replacement of sucrose with alternative sweeteners. Researchers have used time–intensity (TI) evaluation to understand how the different sensory characteristics of dairy products like chocolate sweetened with sucralose, rebaudioside and neotame,[11] chocolate ice-cream sweetened with sucralose and stevia,[12] mango skyr yoghurt sweetened with stevia, thaumatin and blends of the two[13] changed over time. Although TI can measure the rate, duration and intensity of a sensory attribute over a specified time, techniques like temporal dominance of sensations (TDS) and temporal check all that apply (TCATA) can provide a complete temporal profile of attributes like taste, flavour and texture within a single session by panelists.[14,15] TDS methodology has been successfully used to determine the changes in sensory perception of food products such as mango skyr yoghurt sweetened with stevia and thaumatin,[13] lemonade sweetened with stevia,[16] chocolate dairy dessert sweetened with sucralose, aspartame, neotame and stevia,[17] and fat-free strawberry yoghurts.[18] However, a recent study found that 'dominance' is a complex term related to several aspects of perception, and its different conceptualizations among panellists and assessors can significantly impact the interpretation of results.[19] Moreover, the sequential selection of attributes in TDS can result in loss of significant sensory information, especially in complex products that stimulate multiple sensations simultaneously during consumption.[20] Therefore, TCATA can provide a more comprehensive description during the dynamic sensory characterization of food products as one or more applicable attributes can be determined at a given time during consumption.[21]

TCATA has been successfully used to characterize the dynamic profile of food products formulated with reduced sugar or replaced sugar. Oliveira *et al*.[22] found that chocolate milk formulated with 20% sugar reduction (7.2% sucrose) showed a significant decrease in the citation frequency of sweetness evaluated by TCATA compared to milk formulated with 9% sucrose (without any sugar reduction). In another study, Harwood and Drake[9] used TCATA evaluation and found that protein beverages formulated with stevia and monk fruit showed higher area-under-curve values for bitterness, astringency and metallic taste compared to beverages formulated with sucrose. Maheeka *et al*. further found that as the sucrose content decreased from 6% to 4% and from 4% to 1% in vanilla milkshake, citation proportion for sweetness, creamy flavour, creamy mouthfeel, astringency, mouthcoating and liquorice increased, when evaluated using multi-sip TCATA by both expert and consumer panels. In real life, products are consumed in rapid repeated bites, which can change how they are perceived due to sensory adaptation.[23] Therefore, one intake only may not be enough to perceive all the sensory sensations in a product, particularly complex ones. However, the majority of research that used TCATA to investigate changes in the temporal profile of food products formulated with alternative sweeteners generally only focused on a single intake.[9,22,24] Multiple-intake TCATA has only been used in a study that investigated the effect of sucrose reduction on the temporal profile of vanilla milkshake.[25] Therefore, the novelty of the present study lies in the fact that a multiple-intake TCATA approach was used to provide a realistic sensory experience when consuming yoghurt formulated with varying concentrations of sucrose, xylitol and stevia.

Researchers have explored the incorporation of fruit purees as a means of sugar reduction and improvement of sensory properties. The impact of incorporating soursop puree on the sensory attributes of yoghurt has been investigated.[26] The authors found that yoghurt formulated with 50% puree and 75% sugar, when pasteurised at 80 and 43 °C pasteurization temperature, had similar scores for taste, flavour and overall acceptability compared to yoghurt formulated with 0% puree and 100% sugar, pasteurized at 90 and 41 °C. Recently, another study examined the effect of supplementation of camel milk yoghurt with various fruit purees (apricot, blueberry, pineapple, peach or strawberry) on sensory properties.[27] Results showed that yoghurts supplemented with 5% fruit puree had similar scores to control (0% puree) in terms of fruity odour and flavour. It is important to note that past research predominantly focused on the incorporation of fruit puree in products sweetened with sucrose, rather than alternative sweeteners.

The use of sugar substitutes and multisensory integration are effective approaches to reduce sugar. In this research, a combination of these approaches was used to investigate the effect of different natural sugar substitutes and strawberry puree addition on the temporal sensory changes of sugar-replaced fruit yoghurt using the multiple-intake TCATA method. It is hypothesized that the use of different sweeteners and varying concentrations of strawberry puree added to the yoghurt will have a significant impact on the temporal changes in sensory attributes and liking of the product.

MATERIALS AND METHODS

Ethics statement

Ethical approval (20/73) for this study was provided by the Auckland University of Technology Ethics Committee (AUTEC). All participants provided a written consent before the commencement of the data collection.

Participants

A total of 40 participants between 18 and 50 years of age participated in this study. Participants were selected through poster advertisements around the campus and on social media networks (Facebook and Instagram). Participants were informed that they would be required to eat a strawberry yoghurt sample sweetened with sucrose or natural alternative sweeteners through poster advertisements. Participants who expressed an interest in the current research were screened for their yoghurt consumption by asking them if they consumed yoghurt in their daily lives. They were asked to respond with a 'yes' or 'no'. Those who answered affirmatively were further invited to participate in the current research. They were rewarded with a supermarket voucher for their participation in the study. Participants who followed vegan, vegetarian or kosher diet, had food allergies or any other medical conditions associated with food were excluded from this study. Data collection was carried out over a 3-month period (January–March 2021). Both training and data collection were done between the hours of 9:00 am and 1:00 pm on weekdays in the sensory laboratory located at the Department of Food Science, Auckland University of Technology.

Sample preparation and presentation

Greek-style natural yoghurt from Yoplait (Lion-Dairy & Drinks (NZ) Ltd, Palmerston North, New Zealand) purchased from Countdown, Auckland, New Zealand was used in this study. 100% natural strawberry fruit puree was obtained from Doehler Ltd, Australia. Sugar substitutes xylitol and stevia were purchased from iHerb (California, USA) and sucrose was obtained from a local supermarket (Countdown, Auckland, New Zealand).

Yoghurt samples with varying concentrations of sweetener and fruit puree were formulated in this study. Preliminary studies were carried out to determine the maximum sweetener concentration in relation to sucrose based on the 'difference from the reference method', as previously carried out according to our earlier work.[29] A total of 15 panellists ranging in age from 21 to 50 participated in the evaluation. Yoghurts sweetened with two different concentrations of natural alternative sweeteners, namely xylitol (9% and 10%) and stevia (0.15% and 0.20%) were prepared and evaluated. Participants were instructed to taste the reference sample, which contained 9%, and then evaluate the sweetness intensity of the other samples. Participants were instructed to compare yoghurt sweetened with alternative natural sweeteners to the reference yogurt sweetened with 9% sucrose using a linear scale anchored with 0 (much less sweet than the reference), 5 (as sweet as the reference) and 10 (much sweeter than the reference). Using this methodology, it was determined that plain yogurt samples sweetened with xylitol (10%) and stevia (0.15%) had sweetness levels equivalent to that of sucrose (9%). Therefore, yoghurt samples were sweetened with these specific concentrations of sweeteners before the incorporation of fruit puree. Following the addition of fruit puree in yoghurt, adjustments were made to the sweetener concentration to ensure that the overall sweetness intensity remained consistent with the formulation that did not contain any fruit puree.

Determination of the minimum concentration of sweetener and fruit puree employed a systematic approach. The concentrations of fruit puree and sweeteners were adjusted to find the optimal level where sweetness remained detectable while minimizing its overall presence. The aim of this approach was to achieve a balance between enhancing sweetness with fruit puree and sweeteners and ensuring that the sensory attributes of the product met the desired criteria. This was done by maintaining sweetness perception at the lowest concentration of both sweetener and fruit puree. Table 1 summarizes the concentrations of fruit puree and sweetener used to formulate the yoghurt samples in this study.

Strawberry yoghurt samples were placed in polystyrene cups and were stored in a commercial-grade fridge (Fisher & Paykel, East Tamaki, New Zealand) at 4 °C for 24 h prior to testing to ensure sample consistency. After 24 h, samples (50 g each) were presented in plastic containers coded with a three-digit random code, with presentation randomized and counterbalanced across participants.[28]

Multiple-intake TCATA

The multiple-intake TCATA procedure in this study over three intakes[25] adapted the methodology reported by Castura *et al.*[21] The intensity scales were replaced with buttons corresponding to the eight different sensory attributes in this study. These attributes were defined and references for the attribute were selected in an open discussion with the panellists (Table 2). The TCATA data were binary coded across time, with '0' corresponding to unselected attribute and '1' to selected attribute. For all the applicable attributes, unlimited selections and reselections were allowed, and participants were instructed to not select any attribute when no sensations were perceived.

Panel training

Panel training was carried out over three different sessions over 10 h. In the first session, panellists were instructed to familiarize themselves with different kinds of sensory sensations associated with yoghurt and their measurement using a multi-sip TCATA procedure. Panellists evaluated the changes in the sample by checking and unchecking attributes in such a way that the attributes selected would best describe the sample at a particular time. Panellists were also familiarized with definitions of the different sensory attributes (Table 2). During training, panellists were informed that they were free to select multiple attributes simultaneously when more than one attribute was considered applicable to describe the sample at any given moment.

In the second session, panellists consumed three strawberry yoghurt samples formulated with either sucrose, xylitol or stevia. They listed all the sensory sensations associated with each sample. In the third session, a dummy multi-intake TCATA trial was carried out, which allowed the panellists to evaluate strawberry yoghurt samples formulated with sucrose over 45 s. This allowed panellists to familiarize themselves with the computer interface. During training, the panel leader actively reinforced participants' understanding of the TCATA procedure and assisted them wherever necessary.

Evaluation procedure

Panellists were invited to attend the actual evaluation of strawberry yoghurt samples sweetened with sucrose, xylitol and stevia using the TCATA method once they completed their training. Sensory testing of the fruit yoghurt sweetened with sucrose, xylitol and stevia (Table 1) was carried out in three separate sessions. All three sessions were performed in the sensory booths of a sensory laboratory. Panellists evaluated each sample over three different intakes, aided by on-screen instructions. They selected the appropriate sensory attributes that best described the sample by clicking on the buttons displayed on the screen, over a time-period of 45 s. Participants were provided with the definitions and references of all eight sensory attributes (Table 2) that were evaluated in the current study. Once panellists were seated in the sensory booth, they clicked the 'START' button on the left-hand side of the screen. Panellists were instructed to take a spoonful of sample and keep it in their mouth for 20 s. The time period of 20 s was chosen in accordance with our previous research, which carried out a temporal dominance of sensations (TDS) evaluation of plain yoghurt sweetened with different sweeteners.[29] Panellists were then asked to swallow the sample. The on-screen instructions helped minimize the variation in panellists' eating behaviour to ensure each panellist consumed the yoghurt sample in a similar way. Panellists were asked to continuously select and deselect the sensory attributes that best described

Table 1. Concentration of sweetener and fruit puree for each strawberry yoghurt sample

Sample ID	Concentration of sucrose (%)	Concentration of xylitol (%)	Concentration of stevia (%)	Concentration of fruit puree (%)
Sucrose A	5.16	—	—	11.5
Sucrose B	5.16	—	—	18.5
Sucrose C	8.34	—	—	11.5
Sucrose D	8.34	—	—	18.5
Xylitol A	—	7.86	—	11.5
Xylitol B	—	7.86	—	18.5
Xylitol C	—	9.63	—	11.5
Xylitol D	—	9.63	—	18.5
Stevia A	—	—	0.16	11.5
Stevia B	—	—	0.16	18.5
Stevia C	—	—	0.19	11.5
Stevia D	—	—	0.19	18.5

Table 2. Definition and references of the attributes used for TCATA evaluation of fruit yoghurt

Attribute	Definition	Reference
Sweet	Sensation associated with the presence of sugars	2% sucrose solution
Sour	Sensation associated with the taste of fermented dairy products	0.08% citric acid solution
Bitter	Sensation associated with bitter taste	0.05% caffeine solution
Creamy	Sensation associated with full, soft, and smooth texture	Milk with 20% added milk cream
Fruity	A sweet, floral, aromatic blend of variety of ripe fruits	100 mL of kiwi and strawberry juice in a 1-oz cup
Mouthcoating	Sensation associated with adhesion of the product to the palate and teeth	Sour cream
Liquorice	Lingering effect elicited by liquorice roots	10% alcohol solution
Astringent	Sensation associated to a dry and rough feeling on the tongue and oral cavity	Tannic acid (3.0 g L^{-1}) in water

the sample. They were allowed to select the same attribute repetitively, or not select an attribute at all, concurrently over a time period of 45 s. After TCATA evaluation of the first intake, panellists rated overall liking of the sample using a 9-point hedonic scale anchored by 'extremely dislike' on the left-hand side and 'extremely like' on the right-hand side.[30] The same steps were followed to obtain the TCATA evaluation and hedonic rating for second and third intakes without any break. In this way, three TCATA profiles and three hedonic ratings were obtained for each sample evaluated. The panellists were instructed to wait 30 s between different yoghurt samples and were requested to cleanse their palate by consuming water cracker and filtered water to minimize carryover effects. Data were collected using Fizz Acquisition software (Version 2.46b, Biosystèmes, Couternon, France).

Data analysis

All univariate and multivariate analyses in the present study were performed using XLSTAT sensory software (Addinsoft, Long Island City, NY, USA).

Aligned rank transformation (ART)–analysis of variance (ANOVA)

In order to retain the familiarity and interpretability of the familiar parametric *F*-test (ANOVA), an analysis for the non-parametric data called aligned rank transformation (ART) was used for the present research.[31,32] It is worth highlighting that the integration of ART–ANOVA in the current research represents a significant advance in the analysis of temporal TCATA data. Previous studies that have utilized TCATA in sugar reduction studies have primarily relied on the analysis of data using TCATA curves alone.[9,22,33,34] While the use of TCATA curves alone is a valuable tool for exploring temporal sensory data, they are particularly suitable for simpler scenarios with one primary factor, such as sweetener type or varying sweetener concentration. When dealing with more complex datasets involving multiple factors or interactions, the use of parametric tests like ART–ANOVA becomes essential. Parametric statistical methods are necessary for understanding the main and combined effects of factors and interactions that are challenging to identify using one-way non-parametric method like Friedman's test. Our dataset obtained from the evaluation of the effects of varying concentrations of fruit puree and sweetener on dynamic changes in yoghurt sensory perception is an example of a complex dataset. Therefore, the current research employed ART–ANOVA to analyse temporal sensory data with an aim of detecting significant differences and interactions that might have been missed using non-parametric statistical techniques.

ART first aligns all the responses ($Y_{aligned}$) for each possible main effects or interaction and then assigns the mid-ranks to all the $Y_{aligned}$ responses (Y_{art}) using *ARTool* version 2.1.0 (University of Washington, Seattle, WA, USA). Once aligned and ranked, the data can be analysed just as parametric ANOVA, with the exception that the response variable can be ordinal or continuous and without normal distribution.

ART–ANOVA was carried out on TCATA sensory duration data to inspect the differences in the duration of the cited attributes in the products and within the three intakes. Using the duration of each applicable attribute as explanatory variable, multi-intake TCATA data were analysed according to the following model[31]:

$$\text{Duration} = \text{Participants} + \text{Product} + \text{Intake} + \text{Participants} \times \text{Product} + \text{Participants} \times \text{Intake} + \text{Product} \times \text{Intake}$$

where, Duration means the time (in seconds) of each applicable attribute, Participants is a random effect, and Product and Intake were set as fixed factors. Tukey's multiple comparison tests were applied when ART–ANOVA results were significant to determine if significant differences ($a = 0.05$) existed between means.[32]

Correspondence analysis (CA)
CA was applied to standardized TCATA data to envision the sum durations of selected sensory attributes over an average of three intakes in each product. The sum duration was calculated by adding up the total TCATA count of each attribute over an average of three intakes for each product as a function of time for all the panellists. This analysis allowed the projection of sensory attributes onto a simple visual map.[21] Moreover, a chi-square test of independence between columns (i.e., different yoghurt samples) and rows (i.e., sensory attributes) was carried out to determine if significant differences existed across different yoghurt samples formulated with varying concentrations of fruit puree and sweetener in terms of sensory attributes.

Dynamic liking
A mixed ANOVA was performed on the results for overall liking. Tukey's multiple comparison tests were carried out for the ANOVA results that reached statistical significance ($P < 0.05$).

Temporal drivers of liking (TDL)
TDL were calculated according to Thomas *et al*. on temporal sensory data obtained with TCATA. For each sensory attribute per product, an individual liking-while-applicable (LWA) score was computed by calculating the average liking scores given by the panellists to the attribute's citation duration. This average was then computed over selections of the attribute and was weighted by its duration over the three intakes. From the LWA score of each sensory attribute per product, centred liking-while-applicable (CLWA) scores were calculated by the subtraction of average liking scores weighed by the individual intake duration. CLWA scores for each sensory attribute were averaged for the number of consumers who cited the certain attribute as applicable. Nullity of all these CLWA averages was analysed by *t*-test using XLSTAT sensory software (Addinsoft), in which number of degrees of freedom is equal to the number of participants quoting a particular attribute for a particular product minus 1. When the obtained *P*-value was significantly higher than the theoretical mean of zero, it signified a positive temporal driver of liking.[35]

RESULTS

Effect of multiple intakes on the cited sensory attributes as evaluated by TCATA

Table 3 shows the ART–ANOVA results for the transformed values of each sensory attribute for each yoghurt product sweetened with sucrose with each intake. All the attributes showed a significant $F_{(\text{Intake})}$ effect except for *creamy* in Sucrose A, *sour* in Sucrose B and *sweet* and *fruity* in Sucrose C. Attribute *sweet* was significantly higher in the first intake compared to second and third intakes for Sucrose A, B and D. *Sour* showed a significant $F_{(\text{Intake})}$ effect for Sucrose A, C and D, with a decrease from first to third intake in all three yoghurt products. Attribute *bitter* also showed a significant decrease from the first to third intake in all yoghurt samples sweetened with sucrose. Moreover, attribute *creamy* showed a significant decrease from first to third intake in Sucrose C and D. Attribute *fruity* was significantly the highest for the first intake compared to third intake in Sucrose B and D. In contrast, for sucrose A sample, fruitiness was significantly the highest for third intake compared to first intake. Attribute *mouthcoating* was significantly highest for the first intake in Sucrose A and C, third intake in Sucrose B, and second intake in Sucrose D. Moreover, in the second intake, *liquorice* was lowest in Sucrose A and the highest in Sucrose B compared to the first and third intake. Sucrose C and D also showed contrasting results for *liquorice*. Sucrose C showed a decrease in the attribute *liquorice* from first to third intake, while Sucrose D showed an increase. Interestingly, attribute *astringent* in Sucrose B, C and D was significantly highest for second intake compared to first and third intake. However, for Sucrose A, astringency was the highest for third intake.

Table 4 presents the ART–ANOVA results for the transformed values of each sensory attribute for each yoghurt product sweetened with xylitol within each intake. All the attributes showed a significant $F_{(\text{Intake})}$ except for *creamy* and *fruity* in Xylitol A and B, and *sour* in Xylitol D. Attribute *sweet* was significantly higher for the first intake compared to third intake in Xylitol B, C and D. *Sour* showed a significant increase from the first to third intake in Xylitol A, B and C. Xylitol A and D showed a contrasting result to Xylitol B and C in terms of *bitter*. Xylitol A and D showed higher bitterness for the third intake compared to first intake whereas Xylitol B and C showed higher bitterness for the first intake compared to third intake. Attributes *creamy* and *fruity* were significantly higher for the first intake compared to third intake in Xylitol C and D. Attribute *mouthcoating* was significantly the highest for the third intake in Xylitol A and C, first intake in Xylitol B and second intake in Xylitol D. In Xylitol C and D, attribute *liquorice* was the highest for second intake followed by the first and third intake. In Xylitol A and B, attribute *liquorice* was significantly higher for the first and second intake, respectively. Attribute *astringent* was highest for the third intake in Xylitol A and C, and the first intake in Xylitol B and D.

Table 5 presents the ART–ANOVA results for the transformed values of each sensory attribute for each yoghurt product sweetened with stevia within each intake. All the attributes showed significant $F_{(\text{Intake})}$ except for *sour* in Stevia B and C, *sweet* in Stevia B and *bitter* in Stevia D. Attribute *sweet* was significantly higher for the first intake compared to third intake in Stevia A and D. In contrast, in Stevia C attribute *sweet* was significantly higher for the first and third intakes compared to the second intake. Attribute *sour* was significantly higher for the first intake compared to the third intake in Stevia A and D. Attribute *bitter* in Stevia A and C showed a significantly higher duration for the third intake compared to the first intake, indicating an increase in bitterness with the progression of intakes. In contrast, Stevia B showed a significantly lower duration of bitterness for the third intake compared to first and second intakes. Attribute *creamy* was significantly higher for the second intake compared to first and third intakes in Stevia A and D. In contrast, Stevia B and C showed significantly higher creaminess for the first intake compared to the third intake. Attribute *fruity* showed a significant decrease from first to third intake in all yoghurt samples sweetened with stevia. Similarly, *mouthcoating* also showed a progressive decrease with repeated intakes as mouthcoating for the first intake was significantly higher than the third intake in all yoghurt products sweetened with stevia except for Stevia A. Interestingly, *mouthcoating*

Table 3. ART–ANOVA results for the transformed values of sensory attributes for different samples of strawberry yoghurts formulated using sucrose as a sweetener within intakes

Sucrose A	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$	Sucrose B	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$
Sweet	828.900a	621.837b	565.212b	**4.603***	*Sweet*	988.975a	870.700b	659.650c	**25.131******
Sour	896.675a	958.912a	763.362b	**11.386******	*Sour*	620.325b	638.550ab	799.850a	2.839
Bitter	1119.775a	1080.900b	851.050c	**167.810******	*Bitter*	1178.363a	1019.950b	587.550c	**271.871******
Creamy	702.337a	644.975a	629.450a	0.372	*Creamy*	745.175a	507.788b	684.375a	**3.924***
Fruity	512.350b	507.125b	751.900a	**3.515***	*Fruity*	1047.800a	750.525b	405.175c	**44.637******
Mouthcoating	1142.525a	899.550b	570.275c	**60.173******	*Mouthcoating*	411.650c	723.475b	991.900a	**27.850******
Liquorice	1209.400a	752.000b	1163.338a	**195.966******	*Liquorice*	677.400b	890.900a	666.525b	**22.390******
Astringent	837.175b	750.925c	1197.450a	**109.961******	*Astringent*	400.750c	1001.050a	664.825b	**65.231******
Sucrose C	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$	Sucrose D	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$
Sweet	820.025a	755.037a	709.250a	1.020	*Sweet*	863.175a	557.550c	719.050b	**13.482******
Sour	921.425a	750.225b	756.400b	**8.192****	*Sour*	824.625a	778.950a	452.050b	**12.802******
Bitter	1184.513a	1045.025b	928.850c	**145.591******	*Bitter*	943.262a	992.675a	834.650b	**16.212******
Creamy	788.150a	906.800a	558.650b	**9.806*****	*Creamy*	890.550a	697.175b	480.925c	**12.205******
Fruity	653.225a	645.575a	732.925a	0.551	*Fruity*	821.750a	642.350b	508.600b	**8.792*****
Mouthcoating	775.975a	431.725b	357.100b	**14.563******	*Mouthcoating*	439.975c	919.475a	620.700b	**22.612******
Liquorice	1106.175a	1054.625b	1009.650c	**18.864******	*Liquorice*	554.150c	823.325b	1051.225a	**78.638******
Astringent	572.700b	922.000a	261.450c	**48.315******	*Astringent*	455.000b	721.475a	404.625b	**11.759******

Note: The formulation of each sample was as follows: Sucrose A (5.16% sweetener and 11.5% puree), Sucrose B (5.16% sweetener and 18.5% puree), Sucrose C (8.34% sweetener and 11.5% puree) and Sucrose D (8.34% sweetener and 18.5% puree). Significance levels: *5%, **1%, ***0.1%, ****0.01%. Different letters indicate significant differences between the sensory attributes (within row) according to Tukey's HSD. Significant *F*-values are in bold type. Mean values per each attribute for each product/intake are provided.

Table 4. ART–ANOVA results for the transformed values of sensory attributes for different samples of strawberry yoghurts formulated using xylitol as a sweetener within intakes

Xylitol A	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$	Xylitol B	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$
Sweet	686.600b	932.700a	732.275b	**9.479*****	*Sweet*	684.750a	798.475a	329.950b	**29.096******
Sour	714.200a	543.512b	472.825b	**4.518***	*Sour*	863.150a	780.575a	571.575b	**7.903****
Bitter	356.650c	475.563b	766.663a	**28.886******	*Bitter*	767.275a	681.325b	610.325b	**7.025****
Creamy	695.550a	682.262a	699.700a	0.038	*Creamy*	844.625a	888.325a	813.612a	1.031
Fruity	738.450a	550.675b	584.100ab	2.325	*Fruity*	546.800a	681.900a	568.150a	1.642
Mouthcoating	522.025c	799.763b	1023.775a	**32.908******	*Mouthcoating*	1105.125a	950.925b	601.375c	**71.508******
Liquorice	960.600a	700.225b	303.500c	**90.561******	*Liquorice*	642.175a	466.525b	698.675a	**10.873******
Astringent	632.075c	804.600b	1155.200a	**107.476******	*Astringent*	898.075a	961.850a	451.600b	**50.167******
Xylitol C	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$	Xylitol D	Intake 1	Intake 2	Intake 3	$F_{(Intake)}$
Sweet	958.900a	932.987a	762.050b	**10.861******	*Sweet*	1069.600a	820.025b	823.050b	**30.168******
Sour	902.025a	672.475b	507.987c	**13.250******	*Sour*	631.125a	519.062a	533.750a	0.786
Bitter	933.400a	529.112b	304.725c	**60.125******	*Bitter*	565.350b	499.475b	774.450a	**6.463****
Creamy	1068.625a	414.125c	653.212b	**37.291******	*Creamy*	984.200a	708.400b	522.675c	**29.049******
Fruity	1015.925a	358.050b	453.712b	**35.835******	*Fruity*	913.875a	857.250ab	781.675b	**3.707***
Mouthcoating	779.250b	500.300c	943.050a	**27.322******	*Mouthcoating*	529.950c	795.713a	649.900b	**13.562******
Liquorice	944.975b	1131.500a	357.525c	**138.400******	*Liquorice*	683.650b	1008.675a	388.800c	**91.180******
Astringent	844.425b	708.450c	1138.400a	**58.424******	*Astringent*	570.800a	546.450a	327.700b	**11.746******

Note: The formulation of each sample was as follows: Xylitol A (7.86% sweetener and 11.5% puree), Xylitol B (7.86% sweetener and 18.5% puree), Xylitol C (9.63% sweetener and 11.5% puree) and Xylitol D (9.63% sweetener and 18.5% puree). Significance levels: *5%, **1%, ***0.1%, ****0.01%. Different letters indicate significant differences between the sensory attributes (within row) according to Tukey's HSD. Significant *F*-values are in bold type. Mean values per each attribute for each product/intake are provided.

was significantly lower in Stevia A for the first intake compared to second and third intakes. Attribute *liquorice* showed a significant increase from first to third intake in Stevia A, B and D. In Stevia C sample, *liquorice* significantly decreased from first to third intake. Attribute *astringent* was significantly higher for the third intake compared to first and second intakes in Stevia B and D. In contrast,

Table 5. ART–ANOVA results for the transformed values of sensory attributes for different samples of strawberry yoghurts formulated using stevia as a sweetener within intakes

Stevia A	Intake 1	Intake 2	Intake 3	$F_{(\text{Intake})}$	Stevia B	Intake 1	Intake 2	Intake 3	$F_{(\text{Intake})}$
Sweet	688.425a	584.137a	326.975b	**7.869****	*Sweet*	645.500a	754.325a	645.375a	1.540
Sour	947.075a	918.512a	508.350b	**23.647******	*Sour*	776.475ab	823.325a	673.450b	3.076
Bitter	327.600b	736.175a	700.725a	**15.268******	*Bitter*	694.450a	594.250a	410.962b	**6.854****
Creamy	714.987b	905.600a	701.675b	**7.134****	*Creamy*	805.525a	876.575a	496.787b	**23.188******
Fruity	1092.975a	794.600b	732.275b	**58.055******	*Fruity*	852.075a	757.200ab	668.637b	**3.750***
Mouthcoating	461.175b	789.125a	694.325a	**9.375*****	*Mouthcoating*	861.300a	900.625a	565.925b	**22.457******
Liquorice	581.800b	385.250c	903.700a	**27.211******	*Liquorice*	445.225b	416.500b	604.400a	**3.244***
Astringent	660.225ab	767.200a	552.200b	**5.322****	*Astringent*	939.450b	449.275c	1060.200a	**70.215******
Stevia C	**Intake 1**	**Intake 2**	**Intake 3**	$F_{(\text{Intake})}$	**Stevia D**	**Intake 1**	**Intake 2**	**Intake 3**	$F_{(\text{Intake})}$
Sweet	687.850a	450.200b	641.113a	**5.638****	*Sweet*	878.750a	630.350b	514.225b	**19.246******
Sour	829.975a	683.000a	724.600a	2.476	*Sour*	830.200a	657.500b	691.875b	**3.611***
Bitter	575.888a	371.575b	743.300a	**7.824****	*Bitter*	631.325a	617.975a	502.900a	1.363
Creamy	1022.450a	572.950b	466.125b	**31.403******	*Creamy*	500.225c	933.438a	730.000b	**22.809******
Fruity	1014.850a	913.875b	677.425c	**42.854******	*Fruity*	1088.800a	890.825b	424.600c	**88.967******
Mouthcoating	1115.375a	575.700b	498.850b	**31.786******	*Mouthcoating*	1046.175a	567.300b	380.650c	**47.622******
Liquorice	892.100a	619.800b	389.525c	**20.292******	*Liquorice*	325.100b	527.600a	601.463a	**4.965****
Astringent	1102.950a	245.650c	790.000b	**114.136******	*Astringent*	440.950c	666.175b	1034.675a	**37.491******

Note: The formulation of each sample is as follows: Stevia A (0.16% sweetener and 11.5% puree), Stevia B (0.16% sweetener and 18.5% puree), Stevia C (0.19% sweetener and 11.5% puree) and Stevia D (0.19% sweetener and 18.5% puree). Significance levels: *5%, **1%, ***0.1%, ****0.01%. Different letters indicate significant differences between the sensory attributes (within row) according to Tukey's HSD. Significant *F*-values are in bold type. Mean values per each attribute for each product/intake are provided.

astringency in Stevia A and C was significantly higher for the first intake compared to the third intake.

Effect of varying concentrations of sweetener and fruit puree on the cited attributes as evaluated by TCATA and analysed using ART–ANOVA

Table 6 presents the transformed values of cited attributes for different samples of strawberry yoghurts formulated using sucrose as a sweetener over three intakes. *Sweet* and *fruity* had a significant main effect at both product ($F = 7.787$, $P < 0.01$ and $F = 5.817$, $P < 0.01$) and intake ($F = 7.320$, $P < 0.0001$ and $F = 4.936$, $P < 0.01$) levels. Attributes *sweet* and *fruity* were significantly the highest for the first intake compared to second and third intakes. In addition, *sweet* was significantly higher for yoghurts formulated with Sucrose A and C compared to Sucrose B. This is supported by results shown in TCATA curves (Appendix S1, Fig. S1), with *sweet* being cited longer in Sucrose A (0–55% Standardised time (ST) and 75–96% ST) and Sucrose C (12–23% ST and 48–94% ST) compared to Sucrose B (35–70% and 72–100% ST). Attribute *fruity* was significantly higher for Sucrose A compared to Sucrose B. This is also supported by results summarized in Appendix S1, Fig. S1, which showed higher maximum citation of *fruity* in Sucrose A sample (59.4% at 84% ST) compared to Sucrose B (47.5% from 73% to 100% ST).

Bitter had a significant main effect at both product ($F = 27.81$, $P < 0.01$) and intake ($F = 386.70$, $P < 0.0001$) levels. Attribute *bitter* showed a significant decrease from first to third intake. *Bitter* was significantly the highest in yoghurt sweetened with Sucrose D compared to other yoghurts sweetened with sucrose. TCATA results (Appendix S1, Fig. S1) further showed that in yoghurt sweetened with Sucrose D *bitter* was cited from 45% to 100% ST, with a maximum citation rate of 20% from 85% to 100% ST. *Sour* and *astringent* had a significant main effect at both product ($F = 10.96$, $P < 0.0001$ and $F = 198.545$, $P < 0.05$) and intake ($F = 29.987$, $P < 0.01$ and $F = 16.158$, $P < 0.0001$) levels. Attribute *sour* was significantly higher in Sucrose B and D (samples made with high concentration of fruit puree) compared to Sucrose A and C. Moreover, *sour* was significantly cited more for first and second intakes compared to the third intake. Higher sourness in Sucrose B and D in the first and second intakes were also observed in TCATA results (Appendix S1, Fig. S1). In addition, the maximum citation rate of *sour* in the first intake was significantly higher for Sucrose B (70% at 100% ST) and D (62.5% from 98% to 100% ST) compared to Sucrose A (37.5% at 100% ST) and C (49.27% at 99% ST). Similarly, maximum citation rate of *sour* was significantly higher for Sucrose B (67.5% from 98% to 100% ST) and D (75% from 91% to 93% ST) compared to Sucrose A (35% at 100% ST) and C (42.5% at 96% ST) in the second intake. Attribute *astringent* was significantly higher for Sucrose D compared to Sucrose A. In addition, *astringent* was most cited in the second intake compared to first and third intakes. Higher citation duration of *astringent* in Sucrose D compared to Sucrose A was also observed in the TCATA results (Appendix S1, Fig. S1) in the second intake (37–100% ST) compared to Sucrose A (44–98% ST).

Creamy and *liquorice* only showed a significant $F_{(\text{Intake})}$ effect. Attribute *creamy* was significantly higher for the first intake compared to the third intake. On the other hand, attribute *liquorice* was significantly higher for the third intake compared to first and second intakes. *Sour* ($F = 3.508$) and *mouthcoating* ($F = 3.303$) showed a significant product × intake interaction at the 1% level. Moreover, attributes *fruity* ($F = 2.366$) and *liquorice* ($F = 2.335$) also showed a significant product × intake interaction at the 5% level. *Sourness* showed a significant decrease from first to third intake in Sucrose A, C and D samples, while *sourness* showed an increase from first to third intake for Sucrose B (Appendix S1, Fig. S4(a)). Attribute *fruity* showed a significant increase from the first to third intake in Sucrose A and C samples, while there was a decrease in fruitiness from the first to third intake in Sucrose B and D samples (Appendix S1, Fig. S4(b)). Attribute *mouthcoating* in Sucrose A and C showed a decrease while Sucrose B showed an increase from first to third intake. Moreover, attribute *mouthcoating* in Sucrose D showed an increase from the first to second intake, and then decreased from the second to third intake (Appendix S1, Fig. S4(c)). In Sucrose A attribute *liquorice* showed the lowest value in the second intake while Sucrose B showed the highest value in the second intake compared to first and third intake. Moreover, attribute *liquorice* in Sucrose C decreased while in Sucrose D it increased from first to third intake (Appendix S1, Fig. S4(d)).

Table 7 presents the transformed values of cited attributes of strawberry yoghurts formulated using xylitol as a sweetener, intakes, and their interaction. Only *mouthcoating* had a significant main effect at both product ($F = 65.70$) and intake ($F = 3.578$) levels at 5%. Attribute *mouthcoating* was significantly higher for the third intake compared to the first intake. Moreover, *mouthcoating* was significantly cited more for yoghurt sweetened with Xylitol C and D compared to Xylitol B. This is supported by TCATA results (Appendix S1, Fig. S2) that showed higher maximum citation rate of *mouthcoating* in Xylitol C and D (30% at 100% ST and 22.5% at 99% ST, respectively) compared to Xylitol B (20% at 96% ST). *Sweet*, *sour*, *bitter*, *creamy*, *fruity* and *liquorice* showed a significant intake effect and non-significant product effect. Attributes *creamy* ($F = 30.54$, $P < 0.0001$) and *fruity* ($F = 17.50$, $P < 0.0001$) were significantly higher for the first intakes compared to second and third intakes. *Sweet* and *sour* were significantly higher for the first intake compared to the third intake. *Liquorice* ($F = 144.33$, $P < 0.0001$) showed a decrease from first to third intake. Attribute *bitter* was significantly higher for the first and third intake compared to the second intake. There was a significant product × intake interaction at the 5% level for *mouthcoating* ($F = 2.443$) and *liquorice* ($F = 2.182$). *Bitter* showed a significant product × intake interaction at the 1% level. Bitterness increased from first to third intake in Xylitol A and D but decreased in Xylitol B and C (Appendix S1, Fig. S5(a)). *Mouthcoating* increased from first to third intake in Xylitol A and C but decreased in Xylitol B. Attribute *mouthcoating* in Xylitol D but increased from the first to second intake and then decreased from second to third intake (Appendix S1, Fig. S5(b)). Attribute

Table 6. ART–ANOVA results for the transformed values of sensory attributes for different samples of strawberry yoghurts formulated using sucrose as a sweetener, intakes and their interaction

Attribute	Sucrose A	Sucrose B	Sucrose C	Sucrose D	F (product)	Intake 1	Intake 2	Intake 3	$F_{(intake)}$	$F_{(product \times intake)}$
Sweet	864.771a	675.083b	807.192a	760.404ab	**7.787****	875.269a	701.281b	663.291b	**7.320******	2.109
Sour	516.450b	778.475a	622.983b	751.952a	**10.960******	815.762a	781.659ab	692.916b	**29.987****	**3.508****
Bitter	643.092b	595.667b	644.283b	745.708a	**27.813****	1106.478a	1034.637b	800.525c	**386.698******	0.573
Creamy	795.054	783.975	841.475	781.337	1.737	781.553a	689.184ab	588.350b	**15.881******	0.473
Fruity	867.817a	709.608b	842.967ab	762.658ab	**5.817****	758.781a	636.394b	599.650b	**4.936****	**2.366***
Mouthcoating	718.446	789.667	737.758	811.467	46.463	691.531	743.556	634.994	9.521	**3.303****
Liquorice	622.454	703.554	649.071	667.758	261.701	886.781b	880.213b	972.684a	**138.868****	**2.335***
Astringent	633.592b	696.317ab	758.008ab	793.325a	**198.545***	566.406b	848.863a	632.087b	**16.158******	1.070

Note: Significance levels: *5%, **1%, ***0.1%, ****0.01%. Different letters indicate significant differences between the sensory attributes (within a row) according to Tukey's HSD. Significant *F*-values are in bold type. Formulation of each sample is as follows: Sucrose A (5.16% sweetener and 11.5% puree), Sucrose B (5.16% sweetener and 18.5% puree), Sucrose C (8.34% sweetener and 11.5% puree) and Sucrose D (8.34% sweetener and 18.5% puree). Mean values per attribute for each product/intake are provided.

Table 7. ART–ANOVA results for the transformed values of sensory attributes for different samples of strawberry yoghurts formulated using xylitol as a sweetener, intakes and their interaction

Attribute	Xylitol A	Xylitol B	Xylitol C	Xylitol D	$F_{(product)}$	Intake 1	Intake 2	Intake 3	$F_{(intake)}$	$F_{(product \times intake)}$
Sweet	660.767	672.342	659.333	617.050	39.540	849.963a	871.047a	661.831b	**36.855******	0.397
Sour	807.700	799.050	788.833	825.350	7.782	777.625a	628.906b	521.534c	**19.229******	1.223
Bitter	604.533	700.996	724.925	703.708	8.865	655.669a	546.369b	614.041a	**6.746****	**2.986****
Creamy	676.742	709.867	754.100	668.817	7.638	898.250a	673.278b	672.300b	**30.539******	0.282
Fruity	774.029	777.329	689.846	713.642	10.984	803.763a	611.969b	596.909b	**17.497******	1.227
Mouthcoating	677.433ab	582.167b	717.329a	712.917a	**65.704***	734.087b	761.675ab	804.525a	**3.578***	**2.443***
Liquorice	703.325	683.600	724.983	690.567	39.485	807.850a	826.731a	437.125b	**144.334******	**2.182***
Astringent	658.683a	764.112a	669.746a	762.979a	**290.728***	736.344	755.337	768.225	0.796	1.772

Note: Significance levels: *5%, **1%, ***0.1%, ****0.01%. Different letters indicate significant differences between the sensory attributes (within a row) according to Tukey's HSD. Significant *F*-values are in bold type. Formulation of each sample is as follows: Xylitol A (7.86% sweetener and 11.5% puree), Xylitol B (7.86% sweetener and 18.5% puree), Xylitol C (9.63% sweetener and 11.5% puree) and Xylitol D (9.63% sweetener and 18.5% puree). Mean values per attribute for each product/intake are provided.

liquorice decreased from the first to third intake in Xylitol A but increased from the second to third intake in Xylitol B. Both Xylitol C and D samples had the highest value of *liquorice* in the second intake compared to first and third intakes (Appendix S1, Fig. S5(c)).

Table 8 presents the transformed values of cited attributes for strawberry yoghurts formulated using stevia as a sweetener, intakes, and their interaction. Only *fruity* and *mouthcoating* had a significant main effect at product ($F = 2.252$, $P < 0.0001$ and $F = 113.02$, $P < 0.0001$) and intake ($F = 22.00$, $P < 0.01$ and $F = 37.062$, $P < 0.0001$) levels. Attribute *fruity* was significantly the highest in yoghurt sweetened with Stevia B compared to Stevia A, C and D. Attribute *fruity* also showed a significant decrease in the duration from first to third intake. Longer citation duration of *fruity* in yoghurt sweetened with Stevia B in the first intake was also observed in TCATA results (Appendix S1, Fig. S3). *Fruity* was cited between 19% and 100% ST in Stevia B compared to Stevia A (38–51% ST and 55–86% ST), C (35–100% ST) and D (25–37% ST and 78–84% ST) in the first intake. *Mouthcoating*

Table 8. ART–ANOVA results for the transformed values of sensory attributes for different samples of strawberry yoghurts formulated using stevia as a sweetener, intakes and their interaction

Attribute	Stevia A	Stevia B	Stevia C	Stevia D	$F_{(product)}$	Intake 1	Intake 2	Intake 3	$F_{(intake)}$	$F_{(product \times intake)}$
Sweet	743.617	743.950	773.250	668.242	8.185	725.144a	604.753b	531.922b	**1.123********	1.881
Sour	674.392	665.733	717.908	697.533	0.749	845.931a	770.597a	649.569b	**34.183********	0.587
Bitter	894.717	805.346	750.317	832.708	7.440	557.316	579.994	589.472	12.461	1.071
Creamy	674.983	607.675	643.208	708.767	3.684	760.797a	822.141a	598.647b	**64.707********	0.280
Fruity	565.842b	754.892a	572.387b	614.983b	**2.252********	1012.175a	839.125b	625.734c	**113.019********	1.996
Mouthcoating	790.008a	642.708b	782.175a	683.925ab	**21.994****	871.006a	708.187b	534.937c	**37.062********	1.627
Liquorice	794.925	786.225	775.479	845.058	7.727	561.056ab	487.288b	624.772a	**0.590***	0.867
Astringent	702.350	757.871	730.417	716.600	43.279	785.894a	532.075b	859.269a	**43.614********	**2.970****

Note: The formulation of each sample is as follows: Stevia A (0.16% sweetener and 11.5% puree), Stevia B (0.16% sweetener and 18.5% puree), Stevia C (0.19% sweetener and 11.5% puree) and Stevia D (0.19% sweetener and 18.5% puree). Significance levels: *5%, **1%, ***0.1%, ****0.01%. Different letters indicate significant differences between the sensory attributes (within a row) according to Tukey's HSD. Significant *F*-values are in bold. Mean values per each attribute for each product/intake are provided.

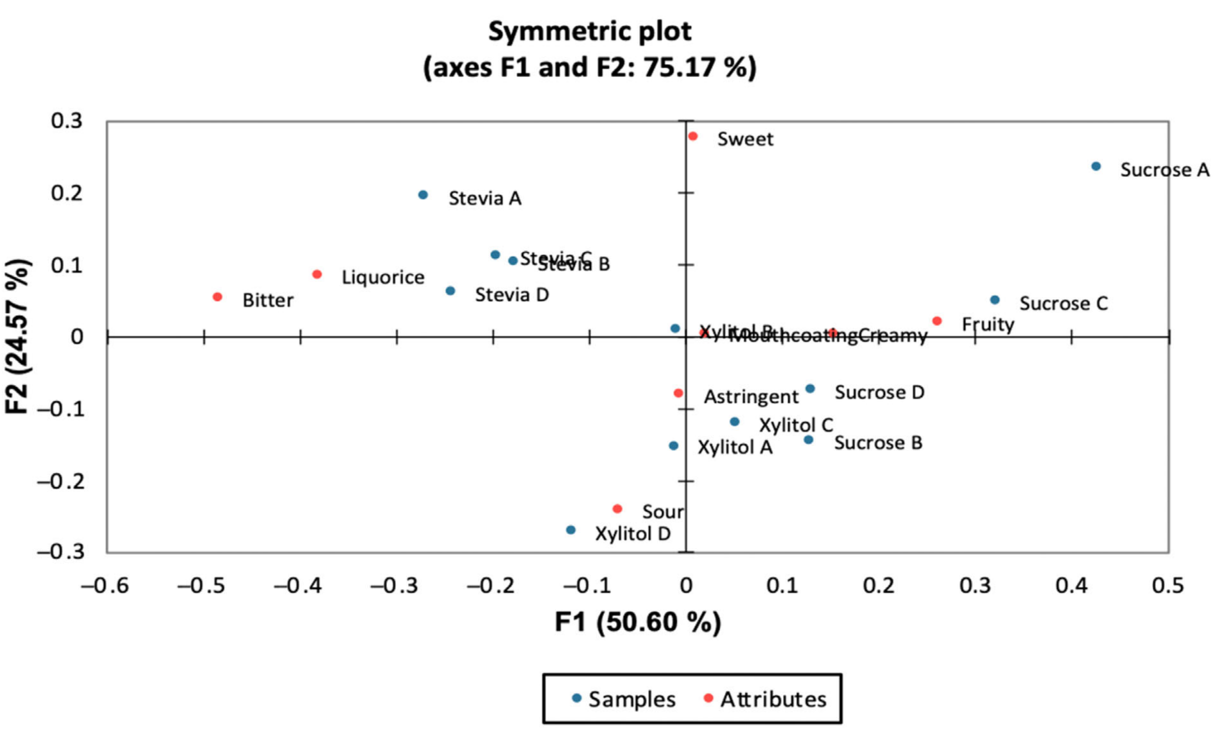

Figure 1. Correspondence analysis (CA) factor map (first two components) based on aggregated temporal check all that apply (TCATA) data for 12 different strawberry yoghurt samples over the whole evaluation duration (0–100 s). Different colours represent the different samples (blue) and sensory attributes (red). The formulation of each yoghurt sweetened with sucrose is as follows: Sucrose A (5.16% sweetener and 11.5% puree), Sucrose B (5.16% sweetener and 18.5% puree), Sucrose C (8.34% sweetener and 11.5% puree) and Sucrose D (8.34% sweetener and 18.5% puree). The formulation of each yoghurt sweetened with xylitol is as follows: Xylitol A (7.86% sweetener and 11.5% puree), Xylitol B (7.86% sweetener and 18.5% puree), Xylitol C (9.63% sweetener and 11.5% puree) and Xylitol D (9.63% sweetener and 18.5% puree). The formulation of each yoghurt sweetened with stevia is as follows: Stevia A (0.16% sweetener and 11.5% puree), Stevia B (0.16% sweetener and 18.5% puree), Stevia C (0.19% sweetener and 11.5% puree) and Stevia D (0.19% sweetener and 18.5% puree).

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was significantly cited more in the first intake compared to second and third intakes. Moreover, *mouthcoating* was cited more in Stevia A and C compared to Stevia B in the first intake, which was also observed in TCATA results (Appendix S1, Fig. S3). The maximum citation rate of *mouthcoating* was significantly higher for Stevia A and C compared to Stevia B; that is, 32.5% at 96% ST and 40% from 91% to 100% ST in Stevia A and C, respectively, compared to 26.7% at 87% ST in Stevia B. *Sweet*, *sour*, *creamy*, *liquorice* and *astringent* showed a significant intake effect and non-significant product effect. *Sweet* ($F = 1.123$) showed a significant decrease in its citation duration from first to third intake at 0.01% level. Attribute *sour* ($F = 34.18$, $P < 0.0001$) and *creamy* ($F = 64.71$, $P < 0.0001$) was significantly higher for the first intake compared to the third intake. *Liquorice* and *astringent* were significantly higher for the first and third intakes compared to the second intake. Table 8 further showed a significant product × intake interaction at the 1% level for *astringent* across all the yoghurts formulated with stevia as a sugar substitute. Astringency decreased from the first to third intake in Stevia A but increased in Stevia D. Moreover, astringency in Stevia B and C decreased from first to second intake and then increased from second to third intake (Appendix S1, Fig. S6).

Correspondence analysis of yoghurts formulated with different sugar substitutes

To further summarize the TCATA results, symmetrical CA was carried out on the sum of durations for which an attribute was selected over an average of three intakes. The results shown in Fig. 1 highlight significant differences in terms of sensory attributes between different strawberry yoghurts formulated with varying concentrations of different sweeteners (sucrose, xylitol, and stevia) and fruit puree ($\chi^2_{(77)} = 2749.26$; $P < 0.0001$). The first two dimensions of the CA factor map accounted for 75.17% of the variation.

Dimension 1 explained 50.60% of the variability and separated the yoghurt samples formulated with sucrose that had positive scores along Dimension 1 from the yoghurt samples formulated with stevia as a sweetener that had negative scores. Sensory attributes like *fruity*, *creamy* and *mouthcoating* were correlated with yoghurts that were formulated with sucrose as a sugar substitute whereas attributes like *liquorice* and *bitter* were correlated with yoghurts that were formulated with stevia as a sugar substitute.

Dimension 2 explained 24.57% of the variance and further separated Xylitol B, which had a low positive score, from Xylitol A, C and D, which had high negative scores. Yoghurt sample formulated with a low concentration of xylitol and high concentration of fruit puree (Xylitol B) was associated with *sweet*. *Astringent* was correlated with yoghurts sweetened with Xylitol A and C, and *sour* was corelated with Xylitol D.

Dynamic liking of yoghurts formulated with different sugar substitutes

The two-way ANOVA model for the results of overall liking for yoghurts sweetened with sucrose, xylitol and stevia showed significant product effects ($F_{3,468} = 195.990$, $P < 0.0001$; $F_{3,468} = 168.877$; $P < 0.0001$; and $F_{3,468} = 36.384$, $P < 0.0001$), non-significant intake effects ($F_{2,468} = 1.308$, $P = 0.272$; $F_{2,468} = 1.738$, $P = 0.178$; and $F_{2,468} = 3.406$, $P = 0.035$), and non-significant product × intake interaction ($F_{6,468} = 1.212$, $P = 0.301$; $F_{6,468} = 1.503$, $P = 0.178$; and $F_{6,468} = 0.386$, $P = 0.888$) effects. Therefore, one-way ANOVA was used to analyse the liking results of yoghurts containing different sweeteners over an average of three intakes (Table 9). Results of one-way ANOVA revealed that, among all the yoghurts sweetened with sucrose or xylitol, the sample formulated with a low concentration of sweetener and fruit puree (Sample A) was significantly liked the most compared to other samples. However, yoghurts sweetened with stevia varying in terms of sweetener and fruit puree concentration were not significantly different from each other in terms of liking.

Temporal drivers of liking

Table 10 summarizes the TDL of all the strawberry yoghurt samples as an average of individual CLWA. Among the different samples of strawberry yoghurts that were formulated using sucrose as a sweetener, *creamy* and *fruity* attributes of Sucrose B (5.16% sweetener and 18.5% puree) significantly decreased ($P < 0.05$) the liking of the product by 0.2 for 87.5% and 72.5% of the panellists, respectively. *Bitter* and *liquorice* significantly decreased ($P < 0.05$) the liking of Sucrose C (8.34% sweetener and 11.5% puree) sweetened yoghurts by 0.2 and 0.3 for 17.5% and 22.5% of the panellists, respectively.

In yoghurt samples formulated with xylitol as a sugar substitute, *sour* significantly decreased ($P < 0.05$) the liking of Xylitol A (7.86% sweetener and 11.5% puree) sweetened yoghurt by 0.1 for 85% of the panellists. In addition, *astringent* significantly decreased ($P < 0.05$) the liking of Xylitol B (7.86% sweetener and 18.5% flavour) sweetened yoghurt by 0.3 for 27.5% of the panellists. Moreover, in all the yoghurt samples formulated with stevia, only *sweet* significantly decreased liking by 0.27

Table 9. ANOVA results showing the effect of varying concentrations of fruit puree and sweetener on the dynamic liking of yoghurts

Type of sweetener	Sample A	Sample B	Sample C	Sample D	$F_{(Product)}$
Sucrose	7.162a	6.145b	6.122b	5.542b	8.642****
Xylitol	5.954a	5.187b	4.904b	4.864b	4.276**
Stevia	4.259	4.597	4.157	3.694	2.405

Note: The formulation of each yoghurt sweetened with sucrose is as follows: Sucrose A (5.16% sweetener and 11.5% puree), Sucrose B (5.16% sweetener and 18.5% puree), Sucrose C (8.34% sweetener and 11.5% puree) and Sucrose D (8.34% sweetener and 18.5% puree). The formulation of each yoghurt sweetened with xylitol is as follows: Xylitol A (7.86% sweetener and 11.5% puree), Xylitol B (7.86% sweetener and 18.5% puree), Xylitol C (9.63% sweetener and 11.5% puree) and Xylitol D (9.63% sweetener and 18.5% puree). The formulation of each yoghurt sweetened with stevia is as follows: Stevia A (0.16% sweetener and 11.5% puree), Stevia B (0.16% sweetener and 18.5% puree), Stevia C (0.19% sweetener and 11.5% puree) and Stevia D (0.19% sweetener and 18.5% puree). Significance levels: *5%, **1%, ***0.1%, ****0.01%.

Table 10. Temporal drivers of liking for each product, average of individual centred liking while applicable (CLWA) and, in parentheses, percentage of judges that cited the attributes present

Attribute	Sucrose A	Sucrose B	Sucrose C	Sucrose D	Xylitol A	Xylitol B	Xylitol C	Xylitol D	Stevia A	Stevia B	Stevia C	Stevia D
Sweet	0.03 (82.5)	−0.04 (57.5)	0.06 (80)	−0.01 (67.5)	−0.11 (57.5)	0.03 (62.5)	−0.08 (62.5)	−0.06 (57.5)	−0.01 (67.5)	0.09 (72.5)	**−0.27 (70)****	−0.01 (57.5)
Sour	−0.14 (55)	0.08 (87.5)	−0.02 (57.5)	0.11 (82.5)	**−0.14 (85)***	0.02 (87.5)	−0.02 (82.5)	−0.09 (90)	0.25 (75)	0.06 (75)	−0.02 (75)	−0.06 (75)
Bitter	0.07 (15)	0.38 (15)	**−0.26 (17.5)***	0.27 (25)	−0.03 (20)	0.18 (25)	−0.03 (35)	−0.06 (42.5)	−0.14 (45)	0.07 (42.5)	0.11 (52.5)	−0.08 (52.5)
Creamy	−0.02 (90)	**−0.21 (87.5)***	0.03 (97.5)	−0.09 (87.5)	−0.08 (62.5)	0.1 (75)	0.14 (72.5)	0.13 (70)	0.09 (55)	0.13 (57.5)	−0.19 (65)	−0.08 (55)
Fruity	0.01 (87.5)	**−0.2 (72.5)***	−0.02 (92.5)	−0.07 (77.5)	0.05 (75)	−0.02 (75)	−0.07 (72.5)	0.14 (62.5)	0.06 (45)	−0.01 (77.5)	0.07 (52.5)	0.03 (55)
Mouthcoating	−0.12 (45)	−0.04 (55)	0.02 (57.5)	−0.11 (50)	0.08 (40)	0.09 (40)	−0.18 (40)	−0.03 (32.5)	0.12 (45)	−0.17 (40)	−0.1 (55)	−0.13 (45)
Liquorice	0.05 (12.5)	−0.11 (22.5)	**−0.34 (22.5)***	0.05 (20)	−0.12 (22.5)	0.25 (25)	−0.09 (22.5)	0.2 (27.5)	−0.15 (45)	0.17 (45)	0.05 (47.5)	−0.01 (52.5)
Astringent	0.15 (25)	−0.3 (25)	0.02 (32.5)	−0.02 (40)	−0.12 (20)	**−0.36 (27.5)***	−0.18 (32.5)	0.05 (30)	0.03 (40)	−0.13 (30)	0.17 (27.5)	0.11 (37.5)

Note: The formulation of each yoghurt sweetened with sucrose is as follows: Sucrose A (5.16% sweetener and 11.5% puree), Sucrose B (5.16% sweetener and 18.5% puree), Sucrose C (8.34% sweetener and 11.5% puree) and Sucrose D (8.34% sweetener and 18.5% puree). The formulation of each yoghurt sweetened with xylitol is as follows: Xylitol A (7.86% sweetener and 11.5% puree), Xylitol B (7.86% sweetener and 18.5% puree), Xylitol C (9.63% sweetener and 11.5% puree) and Xylitol D (9.63% sweetener and 18.5% puree). The formulation of each yoghurt sweetened with stevia is as follows: Stevia A (0.16% sweetener and 11.5% puree), Stevia B (0.16% sweetener and 18.5% puree), Stevia C (0.19% sweetener and 11.5% puree) and Stevia D (0.19% sweetener and 18.5% puree). Significance levels: *5% and **1%. Significance was based on t-test where CLWA is significant compared with theoretical mean of zero. Significant CLWA have been highlighted in bold type.

for 70% of the panellists in Stevia C (0.19 g sweetener and 18.5 g puree).

DISCUSSION

Incorporation of fruit puree impacted the citation frequency of sensory attributes depending on the type of sweetener used

Results from the present work showed that varying the concentration of sweetener and fruit puree had an overall impact on the temporal sensory perception of strawberry yoghurts. The TCATA and ART–ANOVA results showed that strawberry yoghurts formulated using sucrose at low concentration decreased the sweetness and fruitiness when the concentration of fruit puree was increased from 11.5 to 18.5 g 100 g^{-1}. Moreover, irrespective of the concentration of sweetener added, sourness increased when the concentration of fruit puree was increased from 11.5 to 18.5 g 100 g^{-1}. The increase in the citation duration of *sour* with the increase in flavouring was also observed by Oliveira *et al.*[36] as yoghurt formulated with 0.2% of the vanilla or strawberry flavour showed a significant increase in dominance of sour taste and fermented milk flavour compared to samples with 0% or 0.1% flavour. Furthermore, yoghurts formulated with maximum concentration of both sucrose and fruit puree in the present study showed the highest value for astringency and bitterness. Increase in sweetener (sucrose or fructose) or flavour (lemon or strawberry) concentration was found to decrease the citation proportion of astringency in soy-fortified yoghurt as reported by Drake *et al.*[37] However, in this study the authors did not vary both the sweetener and flavour concentration to understand their interaction.

Samples formulated with a high concentration of xylitol (9.63%) showed a higher value for *mouthcoating* compared to samples formulated with a low concentration of xylitol (7.86%). This is consistent with a previous study reporting that ice-cream samples formulated using xylitol had a greater mean score for *mouthcoating* compared to using fructose or erythritol and fructose as a sweetener.[38] Yoghurt samples formulated with a low concentration of stevia (0.16%) and a high concentration of fruit puree (18.5%) showed a higher value for *fruity* attribute and a lower value for *mouthcoating* compared to samples formulated with low concentrations of both sweetener (0.16%) and puree (11.5%). This suggests that incorporation of fruit puree can decrease duration of *mouthcoating* in yoghurts sweetened with stevia. Increased intensity of *mouthcoating* with the use of stevia was also observed by Wu *et al.*[16] The authors found that lemonade sweetened with stevia showed significantly higher citation duration for mouthcoating compared to lemonade sweetened with sucrose, irrespective of the amount of citric acid added.

Incorporation of fruit puree does not impact the sweetness of yoghurt formulated with xylitol or stevia

Interestingly, yoghurts formulated using a low or high concentration of xylitol or stevia as sugar substitute did not show any significant change in the citation duration of *sweet* with increase or decrease in the concentration of fruit puree. This suggests that, unlike sucrose, when xylitol and stevia are used as a sugar substitute in yoghurt, addition of strawberry puree can reduce the amount of sweetener added without any significant impact on the sweetness perception of yoghurt. The ability of strawberry flavour to increase the sweetness of a food product depends on the number of attributes being evaluated.[39,40] This can be due to the dumping effect, which is defined as the inflation of an attribute due to unavailability of other responses.[19] Therefore, the ability of strawberry puree to enhance sweetness becomes more apparent if only sweetness is being evaluated. However, in this study, as other sensory attributes were also evaluated, the enhancement of sweetness due to addition of puree decreased as participants did not associate the increase in concentration of puree with increased sweetness.

Results from the present study confirmed that cross-modal interaction between puree and xylitol or stevia as a sweetener can minimize the negative sensory attributes associated with the use of these alternative sweeteners, without having a significant impact on yoghurt sweetness. To date, the technique of incorporation of flavour has only been used to reduce sucrose in different food products such as chocolate milk,[22] milk desserts[41] and yoghurt.[36]

Multiple intakes had a significant impact on the transformed values of sensory attributes in yoghurts formulated with varying concentrations of sweetener and fruit puree

The multi-sip TCATA approach allowed the identification of differences in the temporal flavour profile strawberry yoghurt sweetened using different sweeteners. The changes in transformed values of the sensory attributes varied with multiple intake of yoghurts formulated with varying concentrations of sucrose (Table 2), xylitol (Table 3) and stevia (Table 4). Similarly, differences between commercially available bitter beverages became more noticeable after repeated tasting. Orange juices formulated with different kinds of sweeteners showed significant differences in perception of sweet, sour and bitter with multiple sips.[42] Similarly, Oliveira *et al*.[22] found that the perception of sweet, rough and bitter varied with multiple sips in chocolate milk. It is important to highlight that none of the studies have investigated the temporal profile of a product formulated with varying concentration of both sweetener and puree using rapid repeated intakes.

Yoghurts formulated using sucrose showed a decrease in the value of the positive attributes like *sweet*, *sour*, *creamy* and *fruity*, and an increase in value of negative *liquorice and bitter* attributes from the first to third intake. This is consistent with Lesme *et al*.[18], who found that 'sweet' and 'sour' were significantly more dominant in the first intake compared to the third intake in strawberry yoghurts sweetened with sucrose due to sensory adaptation. Maheeka *et al*., however, did not find any significant difference in the citation proportions of *creamy* mouthfeel from first to eighth sip of vanilla milk shake formulated either with 6% sucrose or 4% sucrose, contrary to present results. Yoghurts sweetened with stevia also showed a decrease in the value of positive attributes like *sweet*, *sour* and *fruity* from first to third intake, along with an increase in the value of negative attributes *liquorice* and *astringent* from second to third intake. Similarly in other studies, as the intensity of sweet and fruity flavours decreased, metallic and liquorice-like flavours became more apparent in stevia-sweetened products like apple jam,[43] baked goods (cake and biscuit)[44] and apple preserves.[45]

Similar to sucrose and stevia, yoghurts sweetened with xylitol showed a decrease in the value of positive attributes like *sweet*, *creamy* and *fruity*, and an increase in *mouthcoating* from first to third intake. The increase in citation frequency of *mouthcoating* can be attributed to the perceptual interactions as the interactions among decreasing *creamy* and *sweet* taste can possibly increase the perception of the attribute *mouthcoating* over multiple intakes.[46,47]

Substitution of yoghurt with xylitol improved temporal sensory properties irrespective of amount of sweetener or fruit puree used

Xylitol was found to be a better sugar substitute over stevia for strawberry yoghurts because of higher citation proportion of positive attributes like *sweet*, *sour*, *fruity*, *creamy*, and lower citation proportion of negative attributes like *bitter*, *astringent* and *liquorice* (Appendix S1, Fig. S2). On the other hand, strawberry yoghurts formulated with stevia showed an increased citation proportion of negative attributes like *bitter* and *liquorice* compared to xylitol (Appendix S1, Fig. S3). Similarly, Costa *et al*.[7] reported that yoghurt made with xylitol resulted in increased sensory acceptance, retention of textural properties and better probiotic survival compared to yoghurt sweetened with sucralose or stevia. Ribeiro *et al*.[48] recently found that cheese formulated with 6% oat bran and sweetened with xylitol scored significantly more than the cheese sweetened with stevia in terms of overall acceptance. It is worth noting that although attributes like *astringent*, *bitter* and *liquorice* had increased citation frequency in yoghurts sweetened with stevia (0.16% or 0.19%) compared to yoghurts sweetened with sucrose or xylitol, these attributes did not have a significant impact on liking in the present study. Although stevia addition has been reported to decrease liking in protein beverage[9] and yoghurt,[8] these studies used higher concentrations of stevia that have been reported to confer bitter and astringent flavours.[5,49–51]

Strawberry yoghurt formulated with xylitol was a good sugar substitute as there was no significant impact of varying the concentrations of sweetener and fruit puree on the transformed value of positive attributes – that is, *sweet*, *sour*, *creamy* and *fruity* (no significant F-product) – compared to yogurts sweetened with sucrose. As most consumers are unfamiliar with xylitol, it can be used without having any significant impact on other sensory attributes. However, when consumers taste food products sweetened with sucrose, they are able to detect more changes in the sensory attributes resulting from the increase or decrease in sucrose concentration as they are more familiar with sucrose as a sweetener. Stang[52] found that repeated exposure to familiar foods can cause decrease in liking. In contrast, liking for novel carrier food can be increased through repeated exposure.[53]

The number of negative drivers of liking were higher for yoghurts sweetened with sucrose compared to yoghurts sweetened with xylitol. Samples made with low concentrations of sucrose and high concentrations of strawberry puree had *creamy* and *fruity* as negative drivers of liking. Chollet *et al*.[54] also found that increase in the concentration of flavouring (coffee or strawberry) lowered the liking and level of appreciation for yoghurt samples sweetened with 7% sucrose. Moreover, in the present study, yoghurt made with high concentrations of sucrose and low concentrations of puree showed decrease in liking due to attributes *bitter* and *liquorice*. For yoghurts sweetened with low concentrations of xylitol (7.86%), only *sour* and *astringent* were identified as negative drivers of liking for yoghurt made with low (11.5%) and high concentrations of fruit puree (18.5%), respectively. Hence, considering both puree and sweetener concentration is important when developing products using alternative sweeteners.

CONCLUSIONS

The present study was designed to determine the effect of varying concentrations of sweetener (sucrose, xylitol and stevia) and strawberry puree on the temporal sensory profile of yoghurts using multiple-intake TCATA. *Sour* increased with increasing concentration of puree in sucrose-sweetened yoghurts. With increasing puree concentration at low xylitol and stevia concentrations, *mouthcoating* decreased. Yoghurts sweetened with sucrose, xylitol and stevia showed a decrease in *sweet*, *sour, creamy* and *fruity* from first to third intake. However, attributes like *liquorice* and *bitter* in sucrose-sweetened yoghurts, *mouthcoating* in xylitol-sweetened yoghurts and *astringent* in stevia-sweetened yoghurts increased from first to third intake. Yoghurts sweetened with either sucrose or xylitol at low concentrations with low concentration of puree were liked the most. The use of multiple-intake TCATA to determine the temporal changes in flavour can provide valuable information in the development of yoghurts sweetened with alternative sweeteners.

Limitations and future work

The current study has limitations in that it focused primarily on examining the effect of sweetener and fruit puree concentrations at maximum and minimum levels on the temporal sensory profile of yoghurts. This approach did not provide detailed insights into the full range of concentration variations. To address this limitation, future work should expand its investigation to include a wider range of sweetener and fruit puree concentrations. In this way, researchers can gain a deeper understanding of how different concentrations of sweetener and puree can affect the sensory experience of consumers. Moreover, it would be valuable to consider the effect of varying sweetener and puree concentrations on intrinsic sensory cues like perceived healthiness, nutritiousness and freshness, as well as on consumers' purchase intentions. This will allow researchers to capture the nuances of consumer preferences and decision-making related to purchase and consumption of sugar-reduced yoghurts. This holistic approach will provide a more comprehensive perspective on the sensory attributes and consumer behaviour related to yoghurts sweetened with natural sugar substitutes and formulated with fruit puree.

AUTHOR CONTRIBUTIONS

Conceptualization: NH, KK and DC. Methodology: DC, NH and KK. Data collection: DC. Statistical analysis: DC and KK. Supervision: NH. Writing – original draft: DC. Writing – review and editing: DC, NH and KK.

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CONFLICT OF INTEREST

The authors declare that they have no competing personal, financial or professional interest that might have impacted the presentation or the performance of the work described in this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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