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Sugar Replacement in Chocolate-Flavored Milk: Differences in Consumer Segments' Liking of Sweetener Systems Relate to Temporal Perception

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Abstract: Chocolate-flavored milk contributes to excessive intake of added sugars among children and adolescents, which why it is a good candidate product for sucrose replacement. This study investigates how replacing sucrose partially or completely with different sweetener systems affects the sensory profile and consumer liking. Five chocolate-flavored milk treatments were formulated, varying in sucrose replacement level (partial: 58%; complete: 100%) and sweetener system (synthetic: acesulfame-K; natural: rebaudioside M-erythritol blend). Relative-to-Reference Scaling by a trained panel confirmed that no significant differences in the sensory profile when partial sucrose replacement was compared to sucrose, whereas the complete replacement increased bitter taste, pungent flavor, licorice flavor and mouth-drying. A total of 104 consumers evaluated the treatments for liking and indicated their temporal perceptions with temporal check-all-that-apply. Latent variable clustering performed on liking ratings revealed two clusters, which perceived temporal sensory characteristics differently depending on the sweetener system. Cluster 1 preferred the sucrose control over treatments with complete and partial replacement using a natural sweetener system, with complete replacement being perceived as having *off-flavor*. Cluster 2 preferred the sucrose control over partial and complete replacement using either of the sweetener replacements investigated, which were characterized as off-flavored and bitter. Understanding these consumer segments enables the food industry to develop effective low-energy formulations using synthetic and natural non-nutritive sweeteners, leading to reduced sugar consumption.

Keywords: chocolate-flavored milk; sugar replacement; sugar reduction; sweeteners; rebaudioside; acesulfame-K; sensory; temporal; clustering; segmentation



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1. Introduction

Consumers' raising health awareness leads to market demands for sugar-reduced products without compromising on sensory experience. Sugar reduction or replacement with other sweeteners has a significant impact on the sensory properties of food products. In addition to being sweet, sugar plays a crucial role in the product's sensory profile by acting as a flavor enhancer and contributing to its texture and mouthfeel [1]. Changes of the sensory profile of food and beverage products are a typical outcome when completely replacing sugar with non-nutritive sweeteners (NNS), which often leads to lower consumer acceptance of such products. When compared to complete sugar replacement, partial replacement presents an effective strategy for maintaining the sensory profile and acceptance

of food products since it is better at mimicking the sensory profile of sugar-sweetened products [2–4].

Chocolate-flavored milk (CFM) provides a good source of essential nutrients as proteins, fatty acids, vitamins and minerals [5]. However, the inherent lactose from the milk as well as other added sugars contributes to excessive sugar intake in children and adolescents [6,7]. In commercial flavored milks available in supermarkets in Australia, South Africa, and the UK, added sugar contents were found with a mean of 3.7 g/100 mL, contributing to nearly half of the total sugar content [8]. As a result, CFM can be considered a relevant product for sugar replacement, especially in the context of promoting healthier dietary habits and reducing the added sugar consumption. To maintain sweetness in sugar-reduced products, including CFM, NNS are commonly used to replace the reduced sweetness [1,9–11]. Currently, the majority of sugar-replaced products on the market use synthetic NNS, but in recent years, there has been a growing interest among consumers in food products with natural sweeteners [12,13]. The perceived association between “health” and “natural” has contributed to the importance of food naturalness in consumer choices [14]. Several consumer studies investigated the effect of sweetener type and other factors of chocolate milk preferences by choice experiments using conjoint analysis [15,16]. Li, Lopetcharat and Drake [16] investigated parents’ purchase choices for their children when buying chocolate milk and found that natural nonnutritive and natural noncaloric sweeteners were the preferred type of sweetener receiving the highest utility ratings, even higher than sucrose. Brodock, Hayes, Masterson and Hopfer [15] confirmed these findings, and in addition, they indicated that the preference for natural sweeteners such as stevia and monk fruit varied pending on the consumer segment. As a result, natural sweeteners including steviol glycosides from the *Stevia rebaudiana* plant, mogrosides from monk fruit and erythritol that occurs naturally in many fruits and vegetables [17], have emerged as natural alternatives to the synthetic NNS [18].

Sugar-mimicking with NNS is challenged by the presence of undesirable side-tastes and flavors not associated with sugars [10], which include chemical, metallic, licorice, cooling and mouth-drying. Together with sweetness, these sensory qualities also exhibit distinct temporal dynamics within the sensory profile, leading to lingering sensations [4,19,20]. Many studies that investigated temporal profiles of sweeteners have investigated these sweeteners in aqueous solutions and not in complex beverage matrices. However, taste, flavor and texture qualities inherent to a food matrix can interact with the sensory profiles of sweeteners, possibly suppressing or enhancing the sensory qualities associated with the sweeteners [21–24]. Fats, proteins and other components inherent to chocolate-flavored milk are capable of modifying the sensory attributes of sweeteners [24,25]. Due to this complexity of the CFM matrix, it is important to consider how sugar replacement affects the dynamic sensory perception of the actual food products when sweeteners are applied to replace the sugar.

Temporal sensory characterization methods allow us to understand the dynamic of sensory perception and how the sensory attributes of a food product change during consumption. Temporal check-all-that-apply (TCATA) extends the consumer-friendly check-all-that-apply sensory description method by allowing a continuous selection of attributes over a period of time [26]. TCATA is also a rapid method providing a multi-attribute insight into the perception dynamics from a consumer point of view and has proved useful both when characterizing sweeteners and their mixtures in aqueous solutions [4,19,20], as well as sweetener applications in complex beverages [27,28].

The study had the following aims:

1. To investigate how partial or complete sucrose replacement using either a natural or synthetic sweetener system affects the CFM affects sensory profile as well as consumer liking.
2. To explore if individual differences in liking reveal consumers segments with different dynamic sensory perceptions of the sucrose-replaced CFMs.

2. Materials and Methods

2.1. Treatments of Sweetener Systems

The CFM treatments were formulated with a base that consisted of 1.5% cocoa powder (Barry Callebaut Belgium N.V., Lebbeke-Wieze, Belgium) and 0.02% carrageenan (Special Ingredients Ltd., Chesterfield, UK) added to lactose-free semi-skimmed milk (Arla Foods Amba, Viby J, Denmark). Ingredients were mixed and heated to ~70 °C to solubilize the carrageenan and cocoa and then cooled to ~5 °C. All concentrations were calculated as percentage weight/weight (%w/w). Five different combinations of sucrose and two sweeteners were added to the CFM base as shown in Table 1, which provides an overview of the five treatments and concentrations of the sweeteners added in the present study. The control treatment (S) was formulated with the addition of 6% sucrose (Nordic Sugar A/S, Copenhagen, Denmark) to reflect the sugar content of commercial CFM beverages. Two sucrose replacement levels (58% partial replacement and 100% complete replacement of the added sucrose) with an artificial (ace-K) or natural (reb M-erythritol blend) sweetener system were applied: artificial partial (S+A) and complete (A), and natural partial (S+R) and complete (R). In preliminary tastings, the 58% sucrose replacement was chosen to not induce significant changes to the sensory profile, but still provided substantial energy reduction. HOWTIAN LLC (New York, NY, USA) supplied rebaudioside M (reb M), and EASIS A/S (Åbyhøj, Denmark) supplied acesulfame-K (ace-K) and erythritol. Iso-sweetness of the five treatments were tested by a trained sensory panel and will be discussed later in Section 2.2.

Table 1. Added sucrose replacement proportions (%), energy reduction per 100 mL (kcal) and sweetener concentrations for CFM for the sucrose-based control and sugar replaced treatments (partial, 58% and complete, 100%) used in this study. Treatment abbreviations used: sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A), and reb M (R).

Treatment	Added Sucrose Replacement	Energy Reduction/ 100 mL (kcal)	Total Energy/ 100 mL (kcal)	Sweetener Concentration %w/w ¹			
				Sucrose	Ace-K	Reb M	Erythritol
S	-	-	63.3	6%	-	-	-
S+R	58%	-14	49.3	2.50%	-	0.01%	1.60%
S+A	58%	-14	49.3	2.50%	0.02%	-	-
R	100%	-24	39.3	-	-	0.02%	1.60%
A	100%	-24	39.3	-	0.05%	-	-

¹ All sweetener concentrations are reported as weight/weight % as part of the CFM base.

To ensure homogenization, the CFM base ingredients were mixed with an ULTRA-TURRAX® T25 (IKA®-Werke GmbH & Co. KG, Staufen, Germany) for two minutes at 13,500 rpm. After the sweetening agents were added, the mixture was again homogenized for one minute. The samples were stored overnight until use at refrigerator temperature (~5 °C) for a maximum of 3 days at a time.

2.2. Iso-Sweetness Validation and Sensory Profile of Treatments

Relative-to-Reference Scaling (RR) [29,30] was used to obtain a sensory profile of treatments and to confirm iso-sweetness. RR is a modified version of descriptive analysis where the samples are scaled according to a reference sample [30,31]. The sucrose treatment was used as the reference sample and was also included as a blind control in the evaluations. The advantage of using RR to validate iso-sweetness is that the assessor retains a clear memory of reference treatment while evaluating the subsequent treatment, ensuring better discrimination of similar samples. To our knowledge, this is the first time RR has been used to validate iso-sweetness.

RR evaluations were conducted at iSense, Department of Food Science, Aarhus University, designed according to the ISO standards for sensory test rooms [32]. A screened and trained sensory panel [33] of 9 assessors (aged 26–45 years, 5 females) was employed

for RR. The panel received 2 sessions of training before sample evaluation. In the first training session, attributes were generated and a consensus vocabulary on all the samples were established. In the second training session, a subset of samples was compared in pairs, and procedure pilots were performed. Additionally, samples including extremes (CFM with 7% sucrose and 2% added sucrose) were sweetness ranked. Attribute generation and consensus training for RR were conducted following the procedure of generic descriptive analysis [31]. To capture all sensory characteristics, including any long-lasting sensations, the evaluation process involved two sips, each subdivided into an in-mouth and aftertaste evaluation phase, as follows: sip 1 in-mouth (S1m) evaluated while holding the sample in the mouth for 15 s, sip 1 finish (S1f) evaluated at 20 s after swallowing the sample, sip 2 in-mouth (S2m) evaluated while holding the sample in the mouth for 15 s and sip 2 finish (S2f) evaluated at 20 s after swallowing the sample. A description of the attributes selected by the trained panel are presented in Table 2. Assessors were instructed to taste the reference before the evaluation of each sample and as needed. The attributes were evaluated using a computerized 100 mm visual analog scale with three anchors at 0 = “very weak”, 50 = “reference”, and 100 = “very strong”.

Table 2. Sensory attributes evaluated in the Relative-to-Reference Scaling, including their definitions. The evaluation phases were, sip 1 in-mouth (S1m) evaluated while holding the sample in the mouth for 15 s, sip 1 finish (S1f) evaluated after swallowing the sample, sip 2 in-mouth (S2m) evaluated while holding the sample in the mouth for 15 s and sip 2 finish (S2f) evaluated 20 s after swallowing the sample.

Sensory Attribute	Evaluation Phase	Definition	Reference
<i>Flavor</i>			
Overall flavor	S1m, S2f	Overall flavor intensity of the sample as a whole	Definition only
Cocoa powder	S1m, S1f, S2f	Flavor associated with cocoa powder	Definition only
Creamy-fatty	S1m, S1f	Flavor associated with fatty dairy products like cream	Definition only
Nutty	S1m	Flavor associated with hazelnut	Hazelnut aroma (Sosa ingredients, Navarces, Spain)
Caramel	S1m	Flavor associated with caramel	Caramel aroma (Sosa ingredients, Navarces, Spain)
Milky	S1m	Flavor associated with dairy products like milk	Lactose free Arla® LactoFREE semi-skimmed milk (Arla Foods Amba, Viby J, Denmark)
Licorice	S1f	Flavor associated with licorice	0.5% Reb M in aqueous solution
Lactic	S2f	Flavor associated with sour dairy products like sour cream after swallowing	Definition only
<i>Taste</i>			
Sweet	S1m, S1f, S2f	Sweet taste	Definition only
Bitter	S1m, S1f, S2f	Bitter taste	Definition only
<i>Mouthfeel</i>			
Mouthcoating	S1f, S2m, S2f	Degree to which the product is coating the oral cavity	Definition only
Mouthdrying	S1f, S2m, S2f	Degree to which the product creates dryness in the oral cavity	Definition only
Pungent	S1f	Degree to which the product creates an irritation in the oral cavity	0.5% Reb M in aqueous solution
Grainy	S2m	Amount of distinct loose particles in the product mass which have grainy/dusty texture	0% sucrose CFM
Viscosity	S2m	Flow of the sample in the mouth like skimmed milk	Definition only
Mouthwatering	S2m	Degree to which the product creates salivation	Definition only
Cooling	S2f	Degree to which the product creates a sensation of reduced temperature in mouth	Definition only

Each 30 g of sample was served at ~10 °C in a 40 mL transparent plastic tube with a screw cap (Corning® Gosselin™ TP30C-012, Corning, NY, USA) labelled with a three-digit blinding code. Samples were evaluated in triplicate in three blocks and presentation was balanced between assessors following a Williams’ Latin square design. Out of the 9 assessors, 8 assessors evaluated the treatments in triplicate, and 1 assessor evaluated the

treatments in duplicate. Between samples, assessors were instructed to thoroughly cleanse their mouth and wait at least 120 s before evaluating the next sample. Still and carbonated water and crackers were provided as palate cleansers. Data were recorded on iPad Air tablets (Apple Inc., Cupertino, CA, USA) using the EyeQuestion® software version 5.0.7.10 (EyeQuestion, Elst, The Netherlands).

2.3. Consumer Liking and Temporal Check-All-That-Apply of Treatments

The consumers were recruited among students at the Campus of Aarhus University, Denmark. In total, 104 consumers (age 19–35; mean age = 23.6; 38 females) were included in the study. Students were recruited to reflect the age of the target population of CFM. The study was conducted in auditoriums under ambient lightning. Consumers were compensated with a small snack choice.

Consumers evaluated liking of the samples; then, following a break, they evaluated the same samples with TCATA. Liking was evaluated on a 9-point hedonic scale (anchors: 1 = “dislike very much”, 5 = “neither like nor dislike”, 9 = “like very much”. In both parts, there was an obligatory 60 s rest between treatment evaluations. The consumers were instructed to divide the sample between the liking evaluation task and the TCATA task using approximately half for each task.

TCATA with a fading time of 8 s was used to evaluate the samples [34]. Prior to evaluation, consumers were presented definitions with product examples of the following attributes: *sweet*, *bitter*, *cocoa flavor* and *off-flavor*. The attributes were chosen as to be relatable with untrained consumers. During the evaluation, consumers were instructed to place the remaining sample in their mouth and click “start” while swirling the treatment. After 5 s, they were instructed to swallow the sample and start checking the attributes to describe the sample. The maximum evaluation time was set to 60 s. To familiarize the consumers with the TCATA protocol, a practice evaluation using a lactose-free semi-skimmed milk sample (Arla Foods Amba, Viby J, Denmark) was completed before the evaluation of the samples. The practice evaluation was required at least once and was available for the consumers to try up to three times. Most consumers performed one practice evaluation.

Aliquots of 30 g sample were served at ~10 °C in 40 mL transparent plastic tubes with screw caps labeled with a three-digit blinding code. Each consumer received a white tray containing five samples, one per treatment, which were presented and evaluated in a randomized design. Tap water was provided for palate rinsing between samples.

After all samples were evaluated, consumers answered demographic and product usage questions regarding age, gender, height and weight, and consumption frequency of beverages, CFM and sugar/reduced/light beverages. They also indicated factors important when buying chocolate milk as well as general knowledge of sweeteners. General knowledge was assessed by asking “how many of these sweeteners do you know?” from a list of the most common synthetic sweeteners. Data were collected on iPad Air tablets using the Compusense Cloud software version 22.0.8 (Compusense Inc., Guelph, ON, Canada).

2.4. Data Analysis

Linear mixed models were fitted to the attribute intensities from the RR data. Treatment was a fixed effect, whereas assessors and assessor-treatment interaction were random effects. Following analysis of variance (ANOVA), Dunnett’s test was applied to compare means between the sucrose treatment and sucrose-replaced treatments.

A linear mixed model was fitted to the liking data and subjected to ANOVA. Treatment was a fixed effect, whereas consumer was a random effect.

TCATA data were segmented into three equal-sized 20 s time periods, namely attack, evolution, and finish [23,35]. The aggregated data allowed an ANOVA modeling approach of the treatment effect on the attributes within each time period [36–38]. Attribute citation proportions were calculated independently for each time period. Citation proportions were then fitted as the dependent variable using the same model fitted to the liking data. These proportional data are binomially distributed. However, [38,39] have shown the validity of

using statistical tests with linear models that assume normal distribution of residuals for such data.

To identify groups with similar directions of liking, consumers were clustered on liking ratings with clustering of variables around latent variable, where consumers were treated as variables [40]. A noise cluster strategy ($K + 1$) was used to set aside consumers that did not fit into the pattern of any cluster [41]. To maintain power in the TCATA data analysis, the threshold value (q) determining the number of consumers to classify as noise were set to exclude a maximum of 15% [41]. To test if clusters differed in liking ratings, the linear mixed models were fitted with cluster $\times$ treatment interaction as fixed effect and consumer nested in cluster as random effect.

Tukey's HSD test was used to compare mean differences in liking and citation proportions of the sucrose treatment between clusters. Dunnett's test was applied to evaluate differences between means of the sucrose treatment and sucrose-replaced treatments for liking and citation proportions. Following the clustering procedure treatment differences were investigated within clusters. Visualization of the significant differences in citation proportions between treatments was inspired by [23].

All analyses were conducted in R version 4.3.3. The following R packages were applied: tidyverse [42] for the manipulation of data and visualization, lmerTest [43] to fit the linear mixed model and to perform ANOVA, emmeans [44] to conduct the Dunnett's test and ClustVarLV [40] to cluster consumers. All statistical analyses were performed at 95% confidence ($p < 0.05$).

3. Results

3.1. Iso-Sweetness and Sensory Profile of the Replacement Levels and Sweetener Systems

To validate the iso-sweetness between the sucrose treatment and sucrose-replaced treatments, RR was used. No significant differences were found for the sweet attribute from the evaluation phases S1m, S1f and S2f between the sucrose treatment and the sucrose-replaced treatments (Table 3), which shows sucrose-replaced treatments and the sucrose treatment were iso-sweet.

Table 3. Mean $\pm$ SD ratings of the sweet and significant attributes evaluated on a 100 mm VAS scale and the treatment effect p -value from the RR results. Results are shown for sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R) and evaluation phases, sip 1 in-mouth (S1m) evaluated while holding the sample in the mouth for 15 s, sip 1 finish (S1f) evaluated after swallowing the sample, sip 2 in-mouth (S2m) evaluated while holding the sample in the mouth for 15 s and sip 2 finish (S2f) evaluated at 20 s after swallowing the sample. An asterisk (*) denotes a significant difference between sucrose treatment and the sucrose-replaced treatments ($p < 0.05$).

Evaluation Phase	Attribute	Treatment Effect p -Value	Treatments				
			S	S+R	S+A	R	A
S1m	Sweet	0.658	51.3 $\pm$ 8.7	49.8 $\pm$ 9.9	51.3 $\pm$ 10.1	47.7 $\pm$ 11.2	51.6 $\pm$ 12.5
	Bitter	0.046	53.5 $\pm$ 5.9	55.4 $\pm$ 6.8	57.6 $\pm$ 8.0	60.6 $\pm$ 10.0	61.9 $\pm$ 12.9 *
S1f	Sweet	0.982	50.1 $\pm$ 8.8	49.8 $\pm$ 8.5	49.1 $\pm$ 11.1	49.0 $\pm$ 10.5	49.7 $\pm$ 12.1
	Bitter	0.008	54.1 $\pm$ 6.6	54.7 $\pm$ 8.0	56.9 $\pm$ 6.2	61.2 $\pm$ 9.2 *	61.2 $\pm$ 9.3 *
	Pungent	0.022	49.6 $\pm$ 10.0	52.8 $\pm$ 11.1	52.9 $\pm$ 10.1	59.4 $\pm$ 11.6 *	53.4 $\pm$ 10.8
	Licorice	<0.001	51.2 $\pm$ 6.2	52.0 $\pm$ 5.7	53.5 $\pm$ 6.4	65.3 $\pm$ 14.0 *	57.6 $\pm$ 10.6
S2m	Mouthwatering	0.018	56.4 $\pm$ 8.5	54.2 $\pm$ 8.3	53.9 $\pm$ 10.0	47.8 $\pm$ 13.6 *	49.5 $\pm$ 9.0
S2f	Sweet	0.433	50.3 $\pm$ 6.7	48.6 $\pm$ 5.9	51.1 $\pm$ 9.7	46.9 $\pm$ 9.9	48.3 $\pm$ 11.2
	Bitter	0.020	54.6 $\pm$ 5.0	56.4 $\pm$ 7.3	55.8 $\pm$ 6.2	60.0 $\pm$ 9.9 *	61.1 $\pm$ 8.8 *
	Mouthdrying	0.042	51.9 $\pm$ 7.5	56.4 $\pm$ 10.2	56.0 $\pm$ 10.4	61.0 $\pm$ 11.2 *	56.6 $\pm$ 10.6
	Cooling	0.008	51.3 $\pm$ 6.0	51.4 $\pm$ 5.1	55.9 $\pm$ 8.2	56.5 $\pm$ 9.6	56.9 $\pm$ 9.6 *

Furthermore, RR results show the iso-sweet treatments differed significantly in sensations other than sweetness (Table 3). These RR results showed significant differences in treatment R containing the natural sweetener system, which had increased intensities of bitter taste (S1f, S2f), pungent flavor (S1f), licorice flavor (S1f) and mouth-drying mouthfeel (S2f). Treatments with partial sucrose replacement (S+R and S+A) were not found to vary significantly from the sucrose treatment in any attribute across the different evaluation phases, independent of the applied sweetener system. On the other hand, treatments with complete sucrose replacement (R and A) were found to have an effect on attributes across all evaluation phases. A decreased intensity of mouthwatering mouthfeel (S2m) was found for treatment R. Treatment A, containing the synthetic sweetener system, had increased intensities of bitter taste (S1m, S1f, S2f) and cooling mouthfeel (S2f).

Figure 1 shows a biplot from the principal component analysis (PCA) of the significant attributes from RR. The first two principal components explain 97% of total variance. Differences between the sucrose treatment vs. the partial and complete sucrose-replaced treatments described most of the variability (87.5%), as displayed in principal component 1. Differences between sweetener systems were described (8.5%) by principal component 2. The attributes licorice and pungent flavor together with mouth-drying mouthfeel were mostly associated with the R treatment, whereas the bitter taste from the different phases and cooling mouthfeel were primarily associated with treatment A. Consistent with the results from the Dunnett's test, the partially sucrose-replaced treatments were more associated with the sucrose control (S).

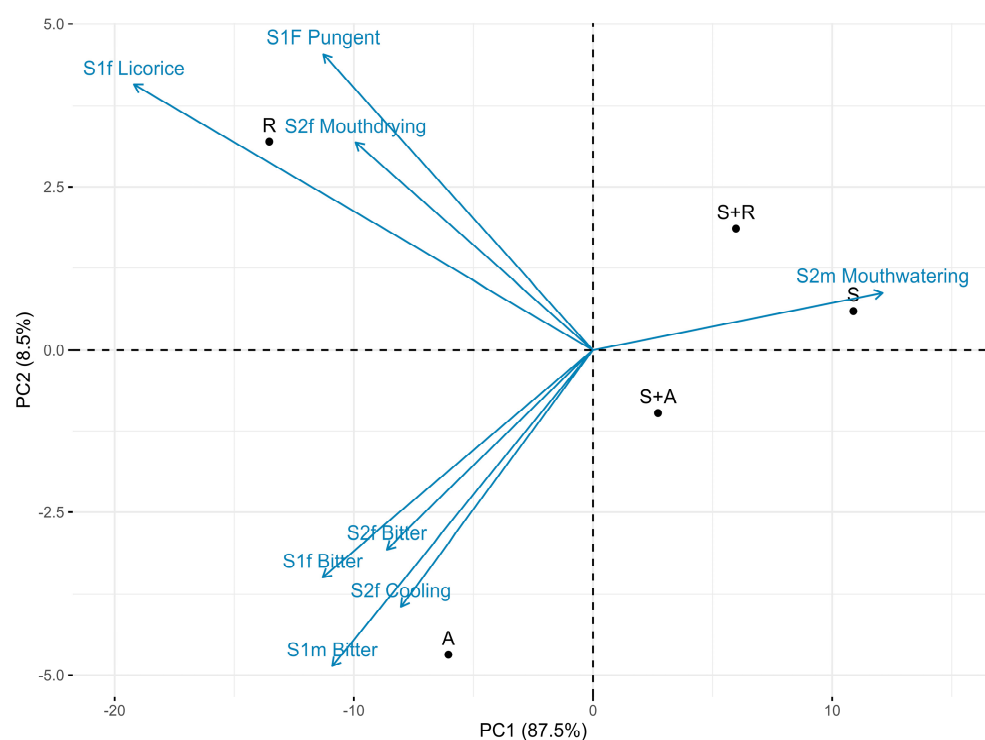


Figure 1. Biplot of PC1 and PC2 from the principal component analysis of the significant attributes from the RR results. Dots represent the treatments while vectors the attributes. Treatments are sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R). The evaluation phases were sip 1 in-mouth evaluated while holding the sample in the mouth for 15 s (S1m), sip 1 finish evaluated immediately after swallowing the sample (S1f), sip 2 in-mouth evaluated while holding the sample in the mouth for 15 s (S2m) and sip 2 finish evaluated 20 s after swallowing the sample (S2f).

3.2. Consumer Liking of the Sucrose Replacement Levels and Sweetener Systems

Violin plots of consumer liking responses (Figure 2) show the sucrose treatment (S) was liked most. Treatments with partial replacement of sucrose, S+A and S+R, did not significantly differ in their liking ratings compared to treatment S, with differences of -0.1 and -0.2 , respectively. Treatments with complete sucrose replacement, A and R, were least liked and significantly different from treatment S (A: diff = -0.6 , $p < 0.01$; R: diff = -0.8 , $p < 0.001$). The violin plots indicate a less homogeneous distributions of the liking ratings in treatments A and R compared to treatment S, S+A and S+R.

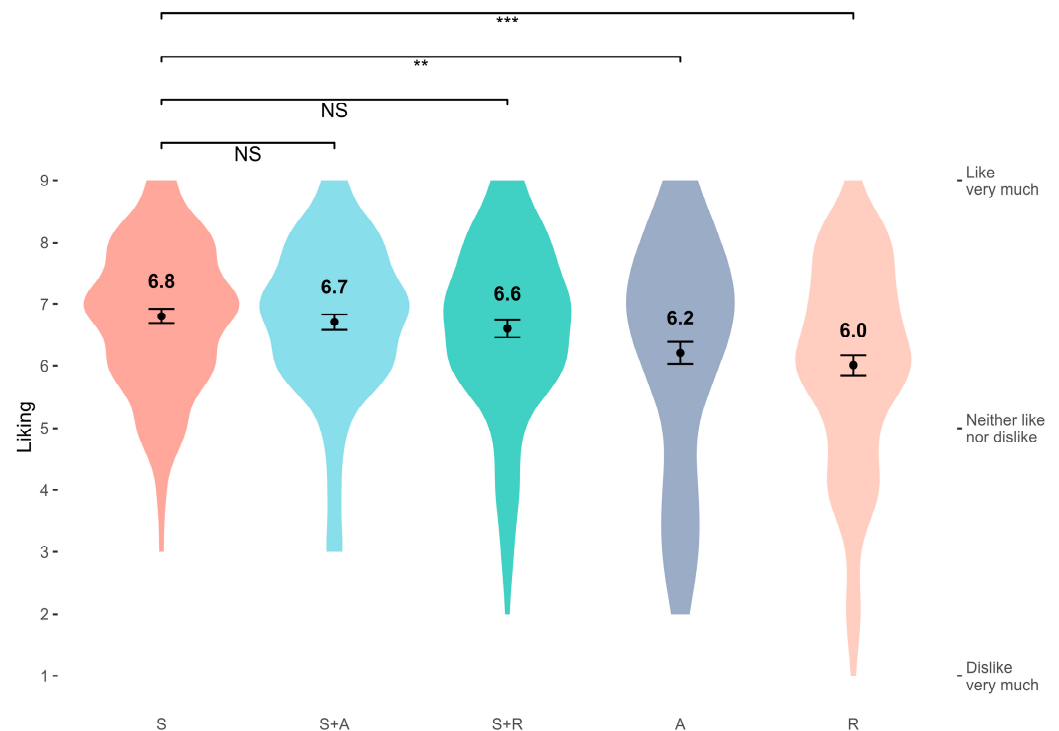


Figure 2. Violin plot with mean and std. error of liking ratings from all consumers. Treatments are sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R). Significant differences between means of the sucrose treatment and sucrose-replaced treatments are indicated with lines above the plot with asterisk: non-significant (NS) = $p > 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$.

3.3. Consumer Temporal Profile of the Sweetened Treatment Systems

Figure 3 shows the citation proportions of the attributes across the three time periods, taking all consumers into account. The highest proportion of the attributes *sweet*, *bitter* and *cocoa flavor* was seen in the attack, followed by a gradual decrease throughout the time periods. *Off-flavor* increased from attack to evolution, followed by a decrease towards the finish. *Sweet* citation proportions did not vary in the attack and evolution.

The partial sucrose-replaced treatment S+R was not significantly different from S in any of the attributes. *Cocoa flavor* in treatment S+A was significantly higher than S in the evolution ($p < 0.01$). *Sweet* and *off-flavor* were significantly higher in treatment A than S in the finish ($p < 0.01$) and evolution ($p < 0.05$), respectively. *Bitter* was significantly higher in R than S in the finish ($p < 0.05$), whereas *off-flavor* was higher than S throughout all the periods, attack ($p < 0.05$), evolution ($p < 0.001$) and finish ($p < 0.001$).

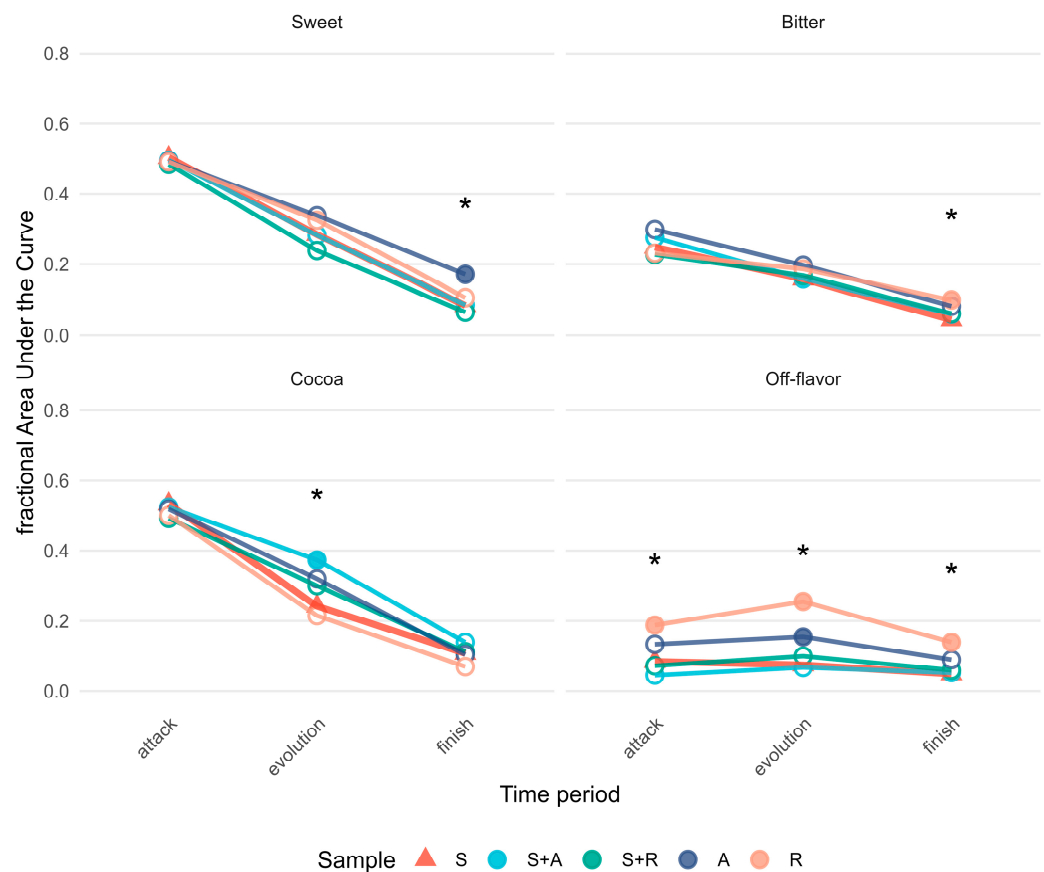


Figure 3. Citation proportions of all attributes in the time periods attack, evolution, and finish considering all consumers. Asterisks (*) indicate time periods with significant differences between sucrose and sucrose-replaced treatments, and significant differences ($p < 0.05$) in Dunnett's test are marked with filled points. Treatments are sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R).

3.4. Consumer Segmentation Based on Liking Ratings

Latent variable clustering was used to segment consumers based on the direction of their liking ratings. The cluster solution was selected based on variation of the optimization criterion. A solution with two clusters was chosen, with 16 consumers (~15%) being assigned to the noise cluster ($q = 0.125$). Consumers assigned to the noise cluster showed increased liking of treatments with partial and complete sucrose replacement compared with the sucrose treatment (Supplementary Figure S1). These consumers were considered atypical and were excluded from further analysis.

The characteristics of cluster 1 ($n = 44$) and cluster 2 ($n = 44$) are shown in Table 4. Overall, the clusters had similar characteristics. Cluster 1 seemed to have a higher intake of non-nutritive sweetened beverages than cluster 2 with a non-significant mean difference of 35.1 days/year (CI: $[-74.9, 4.7]$, p -value = 0.08).

Table 4. Characteristics of consumer clusters. For each cluster, the number of females, mean values of age and beverage intakes are shown.

	Cluster 1	Cluster 2	<i>p</i> -Value
Number of consumers	44	44	-
Number of females (%)	25 (56.8)	29 (65.9)	0.51 ¹
Age (in years)	23.3 ± 2.8	23.8 ± 3.4	0.40
Days intaking CFM per year	33.9 ± 57.2	24.4 ± 28.0	0.32
Days intaking sucrose-sweetened beverage per year	68.9 ± 77.1	71.8 ± 92.5	0.87
Days intaking NNS beverages per year	82.3 ± 105.0	47.2 ± 80.8	0.08

¹ Between-cluster differences were evaluated using chi-squared test (gender) and two-independent sample *t*-test (age, beverage intake).

Figure 4 shows the liking of treatments by the two clusters. The significant cluster-treatment interaction ($F(8, 408) = 24.4, p < 0.0001$) indicates that the two clusters had different preferences. Liking of the S treatment did not significantly differ between the clusters ($p > 0.05$). Cluster 1 liked the sucrose treatment significantly more than both the partial sucrose-replaced treatment S+R (diff = 1.0, $p < 0.001$) and complete sucrose-replaced treatment R (diff = 1.6, $p < 0.001$). Treatments S+A and A were not significantly different from S. Cluster 2 liked the sucrose treatment significantly more than both the complete sucrose-replaced treatments A (diff = 2.0, $p < 0.001$) and R (diff = 0.9, $p < 0.01$) compared to treatment S. However, S+A and S+R were not significantly different from S.

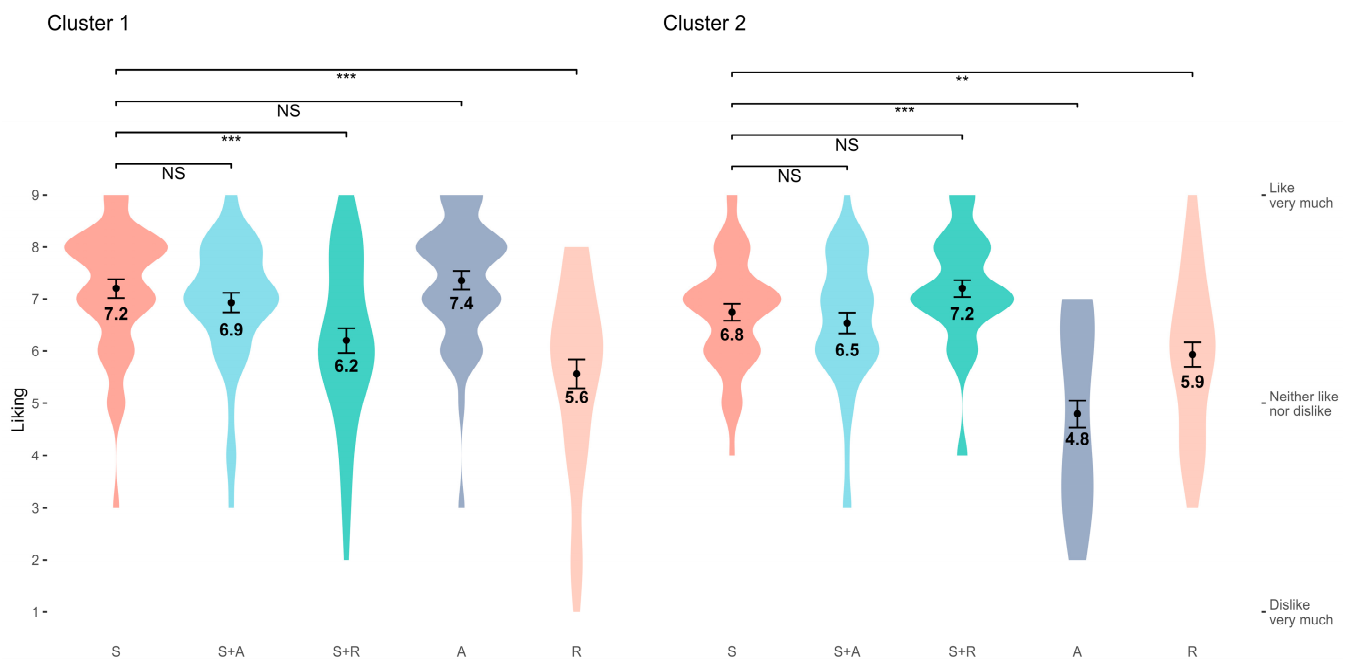


Figure 4. Violin plots with mean and std. error of liking ratings from cluster 1 and 2. Treatments are sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R). Significant differences between means of the sucrose treatment and sucrose-replaced treatments are indicated with lines above the plot with asterisk: non-significant (NS) = $p > 0.05$, ** = $p < 0.01$, and *** = $p < 0.001$.

3.5. Differences by the Clusters in Temporal Profile of the Treatments

Figure 5 shows the citation proportions of the attributes in the different time periods from the two clusters. There was no significant difference between the temporal profile of the sucrose treatment from cluster 1 and 2 ($p > 0.05$) for any attribute across the time periods, indicating the two clusters perceived this treatment in a consistent manner. However,

differences in how clusters perceived the treatments with the different sweetener systems were found.

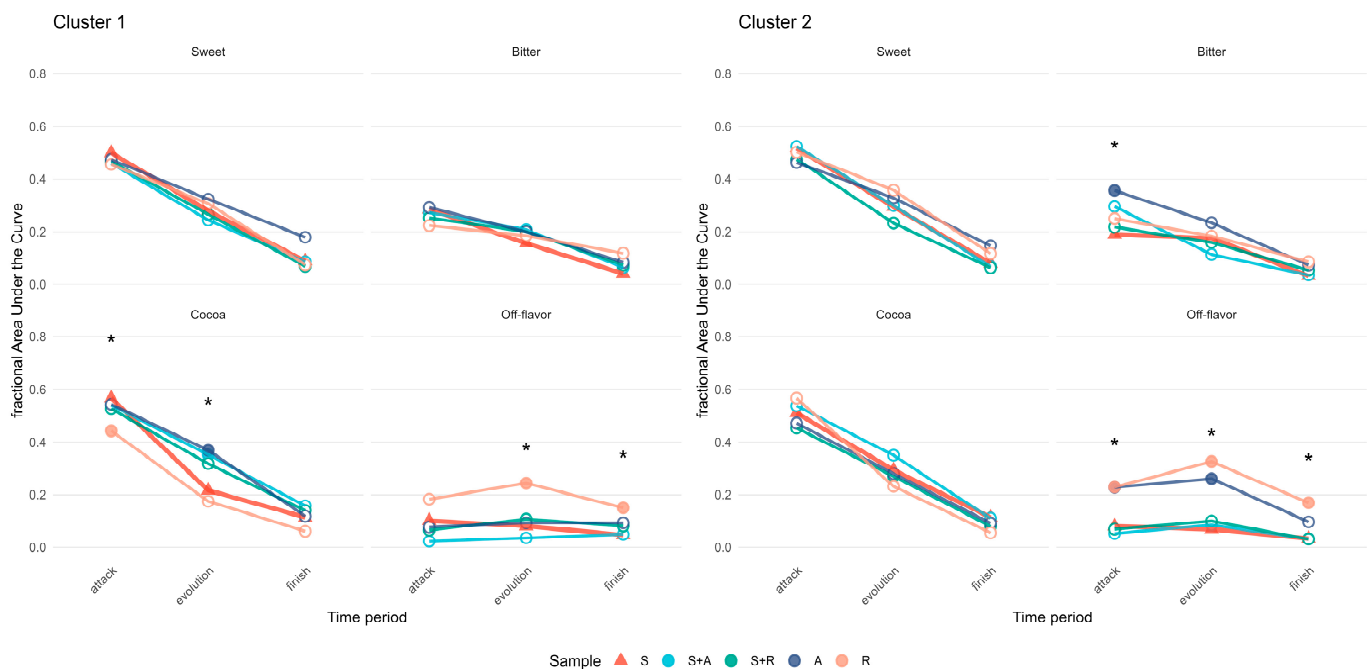


Figure 5. Citation proportions of the attributes in the periods attack, evolution and finish between cluster 1 and 2. Asterisks (*) indicate time periods with significant differences between sucrose and sucrose-replaced treatments, and significant differences ($p < 0.05$) in Dunnett's test are marked with filled points. Treatments are sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R).

In cluster 1, the *cocoa flavor* citation proportion for treatment A was significantly higher than for S in the evolution stage ($p < 0.05$). The *cocoa flavor* citation proportion in treatment R was significantly lower than S in the attack ($p < 0.01$), whereas the *off-flavor* citation proportion was higher than S in both the evolution ($p < 0.001$) and finish ($p < 0.01$) stages. No differences in any attributes were seen between treatment S+R and S+A when compared to S. Taken together with results in Section 3.3, these results show cluster 1 tolerated both partial and complete sucrose replacement when the synthetic sweetener system was applied.

In cluster 2, the *bitter* citation proportion in treatment A was higher than S in the attack ($p < 0.01$) and the *off-flavor* citation proportion was higher than S in the attack ($p < 0.01$) and evolution ($p < 0.01$). The *off-flavor* citation proportion was higher in treatment R than S in all periods, attack ($p < 0.05$), evolution ($p < 0.001$) and finish ($p < 0.001$). Taken together with results in Section 3.3, these results show cluster 2 tolerated partial sucrose replacement but not complete sucrose replacement.

3.6. Factors and Acquainted Sweeteners Affected by Consumers

The clusters differed in their selections of important factors when purchasing CFM (Table 5). Taste and low price were the most and equally important factors for both clusters (98% and 57%, respectively). Naturalness was found important to more consumers in cluster 2 (41%) compared to cluster 1 (23%). Minor differences between the clusters were also seen for allergy/intolerance (cluster 1 = 11%, cluster 2 = 2%) and animal welfare (cluster 1 = 14%, cluster 2 = 9%).

Table 5. Important factors when purchasing CFM by cluster.

Factors	Cluster 1	Cluster 2
Taste	98%	98%
Low price	57%	57%
Thick texture	32%	30%
Naturalness	23%	41%
Climate impact	20%	18%
Brand	16%	18%
Organic	16%	16%
Animal welfare	14%	9%
No additives	11%	11%
Low energy	11%	7%
Allergy/intolerance	11%	2%
Low fat	9%	7%
Other	7%	9%
None	0%	0%

Figure 6 shows the percentage of consumers within each cluster, categorized by number of known sweeteners. Consumers in cluster 2 were found to be acquainted with a higher number of NNS compared to cluster 1. The number of consumers acquainted with 3–6 different NNS was higher in cluster 2, whereas in cluster 1, acquaintance with 0–2 NNS was more frequent.

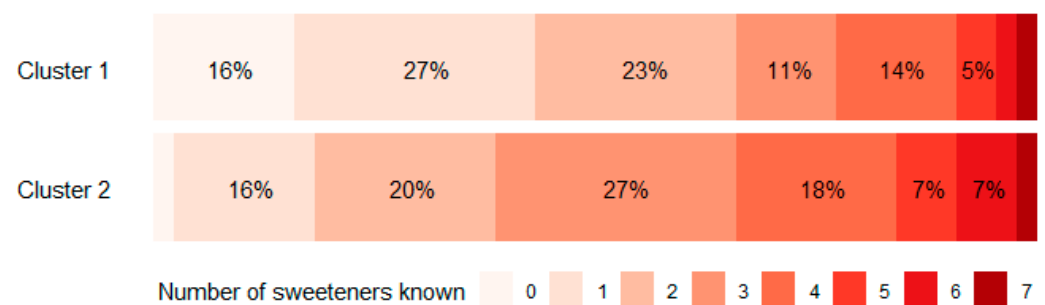


Figure 6. Percentage of consumers in relation to number of NNS known by cluster. The sweeteners listed to choose from were ace-K, aspartame, cyclamate, erythritol, steviol glycosides from the Stevia plant, saccharin and sucralose. Categories with less than 5% are not stated in the figure.

4. Discussion

4.1. Sensory Profile of the Treatments by Relative-to-Reference Scaling

Partial replacement of sucrose had no impact on sensory attributes, regardless of the sweetener system. Pedersen, Bertelsen, Byrne and Kidmose [25] found that in CFM with a similar formulation to S+A did not affect the sensory attributes, except for an increased sweet taste intensity. In the present study, bitter taste was associated with a complete sucrose replacement by ace-K and was present throughout all phases of evaluation. As reported in previous publications, ace-K is associated with an intense bitter taste and aftertaste [4,20,45]. Tan, Wee, Tomic and Forde [24] found an increased bitterness in CFM when replacing sucrose with ace-K. Similarly, Kim et al. [46] found a significant increase in bitter taste of a coffee-milk beverage, with inherent bitterness comparable to CFM when replacing sucrose with 0.035% ace-K. Another study found black tea, a beverage with an inherent bitterness and astringency, to also show increased bitterness when replacing sucrose with ace-K [24].

Completely replacing sucrose with reb M increased licorice and pungent flavor, bitter taste and mouth-drying sensations. Studies have found that reb M has little to no bitterness considering the concentrations used in this study [4,47,48]. Thus, the bitterness of CFM formulated with reb M was likely due to reb M being less effective than sucrose

at suppressing the inherent bitterness of the cocoa [49]. This explanation is consistent with Kim and Hong [50], who found replacing sucrose with reb M increased bitterness in both soy and regular milk systems. They found adding chocolate flavoring increased the sweetness, bitterness and bitter aftertaste, and it neutralized the differences in bitterness and bitter aftertaste between the reb M treatment and the sucrose control, regardless of the milk system. Their finding that bitterness in CFM was similar whether it was sweetened with sucrose or reb M is inconsistent with our finding that CFM was more bitter if sweetened with reb M instead of sucrose. A possible explanation is we used pure cocoa powder to impart chocolate flavor in our study, which is an inherently bitter ingredient, whereas Kim and Hong [50] used other chocolate-flavor ingredients that might have flavor qualities not found in pure cocoa powder. They argued that the sweet dimension of their chocolate flavor, resulting from a congruence between chocolate and sweet taste, could have suppressed the bitter taste. However, learned associations might differ between individuals and cultures [51,52]. Even though trained panels rely on analytical strategies, an alternative explanation could be that the bitter-chocolate learned association is stronger than the sweet-chocolate association among the panelists used in the present study.

We are unaware of studies comparing ace-K to reb M when completely replacing sucrose in a complex matrix. Tan, Wee, Tomic and Forde [24] found replacing sucrose in yogurt with reb A, which is similar to but more bitter than reb M, affected the perception of fewer attributes than replacing sucrose with ace-K. They also found reb M affected the perception of more attributes than ace-K in black tea and CFM, which shows sucrose replacement depends strongly on both the beverage matrix and the sweetening system. Considering the number of attributes affected by reb M in this study, ace-K seems more appropriate to replace sucrose in CFM.

4.2. Consumer Liking of the Treatments

Liking was not maintained with complete sucrose replacement. Kim, Lee and Shin [46] reached a similar conclusion in their study which replaced sucrose with ace-K in a coffee milk beverage. Similar findings were obtained in other matrices, such as a citrus-flavored model beverage [3] and a tamarind beverage [53], where a complete replacement of sugar sweeteners with ace-K failed to maintain consumer liking. Blending ace-K with sucralose or aspartame in synthetic sweetener systems to completely replace sucrose have shown no significant liking differences across various matrices [3,28,54–56]. Using a natural sweetener system with reb M to replace sucrose in samples of ice cream resulted in decreased liking [57]. Other natural sweetener systems with glycoside sweeteners based on stevia and monk fruit have shown varying outcomes [2,28,58,59], likely due to their sensory profile differences when compared to that of sucrose. To maintain an acceptable sensory profile when replacing sucrose with a natural sweetener solution like reb M, only partial replacement might be appropriate, as indicated by the present findings and other studies [2,60].

4.3. Associations between Liking and Temporal Profiles of the Treatments

For the different consumer clusters, liking depended on the specific sweetener system. In cluster 1, replacing sucrose with the synthetic sweetener system maintained liking, regardless of the level of replacement. In cluster 2, partial but not complete replacement of sucrose was possible with either the natural or non-natural sweetening system. Cluster 1 was sensitive to the type of sweetener, whereas cluster 2 was sensitive to the amount of sweetener. Existence of consumer segments with individual liking patterns of sucrose-replaced products have been observed in other studies [3,61–63].

Each consumer cluster perceived temporal characteristics differently depending on the sweetening system. In cluster 1, irrespective of the replacement level, the natural sweetener system containing reb M decreased liking, where complete replacement was associated with lower citation proportions of *cocoa flavor* and increased citation proportions of *off-flavor*. Conversely, complete replacement with the synthetic sweetener system containing ace-K increased liking and increased citation proportions of *cocoa flavor*. Cluster 2 consumers liked

the treatment with complete replacement less, where they found the synthetic and natural sweeteners systems more often perceived *bitter* and *off-flavor*, and *off-flavor*, respectively.

Notably, the lower liking of partial replacement with reb M by cluster 1 was not associated with any changes in the temporal profile. It is possible the temporal profile was unchanged because the attributes that described the difference were not offered in the TCATA evaluations. Alternatively, it might be limitations of the TCATA methodology to detect spike sweetness intensity differences between the samples [64]. Individual differences in preferred sweetness intensity in beverages have been found by others [56,58].

4.4. Individual Differences in Bitter Perception of the Synthetic Sweetener System

When sucrose was completely replaced by ace-K, cluster 2 showed higher citation proportions of *bitter* and *off-flavor* as well as reduced liking compared to consumers in cluster 1. Perceivable bitterness from ace-K has been consistently found at a ~5% sucrose equivalent concentrations and above [3,4,19,20,45,65–67]. The divergence by the clusters in perception of bitterness from ace-K aligns with studies that have shown individual differences in the perception and liking of sweeteners [68]. The perceived bitterness of ace-K is subject to individual variability, as demonstrated in several studies [67,69–71], and these differences are partly attributable to polymorphisms in the TAS2R31 bitter receptor genes [70,71]. Bobowski, Reed and Mennella [70] established a connection between TAS2R31 gene variations and liking differences of aqueous solutions of ace-K, but ace-K concentrations were considerably higher than those commonly found in commercial beverages. Only one study explored the variation in ace-K bitterness perception within a citrus model beverage, revealing a difference between non-tasters and super-tasters of PROP [3]. The present study indicates that the individual differences in the perception of bitterness and liking of ace-K persist even at the concentrations used herein, which is similar to concentrations used when replacing sucrose in beverage formulations.

Additionally, we found increased TCATA citation proportion of *cocoa flavor* in the evolution time period of the partly and completely replaced treatment with ace-K for cluster 1. An explanation might be that consumers in cluster 1 had a low sensitivity towards ace-K bitterness, resulting in higher perceived sweetness, which, through a sweetness-flavor interaction, increased the flavor of cocoa. Such cross-modal interactions of CFM where increasing sucrose concomitantly increased the perception of chocolate flavor have been demonstrated in other studies [25,72].

4.5. Cluster Characteristics

Cluster differences in the reported intake of NNS was found. Consumers in cluster 1 drank beverages sweetened with NNS less often than consumers in cluster 2, who also perceived bitterness more often in CFM containing ace-K. Leksrisompong, Lopetcharat, Guthrie and Drake [62] showed NNS beverage users had higher overall liking ratings for these beverages compared to regular users. Ace-K have been reported as the second most applied NNS in carbonated beverages as suggested by a screening study in the U.S. market [73]. This suggests that NNS consumers are more accustomed to ace-K, which they either liked straightaway or developed a preference over time. Furthermore, more consumers in cluster 2 indicated naturalness was an important factor when purchasing CFM and were more acquainted with different sweeteners than consumers in cluster 1, suggesting that these consumers were more label-conscious and natural ingredient oriented, as indicated by their lower consumption rates of NNS.

4.6. Comparison of Results from Relative-to-Reference Scaling and TCATA

Attribute citation proportions are often roughly proportional to attribute intensities, as citation proportions can be interpreted as the consumers' aggregated perceived intensity of the attributes [64,74]. Consistent with the RR results, no differences in *sweet* TCATA citation proportions were found between the treatments, which adds further confirmation of the iso-sweetness of the treatments. In cluster 2, increased TCATA *bitter* citation proportions in

the attack (0–20 s) of treatment A coincided with the increased bitter taste intensity in the evaluation phases S1m (in-mouth for 15 s) and S1f (swallowing the sample after 15 s) in the RR. However, the increased bitter taste intensity in the evaluation phase S2f in the RR was not associated with increased TCATA *bitter* citation proportions in either the evolution or finish time points.

Complex attributes (e.g., metallic, chemical, licorice, mouth-drying) often used to describe sweeteners can be challenging for untrained consumers to discern as no references are presented [75,76]. In the present study, *off-flavor* was included as an umbrella term to catch attributes not typically associated with CFM. In both clusters, the R treatment was associated with increased TCATA *off-flavor* citation proportions, which coincided with the licorice and pungent aftertaste intensities and mouth-drying mouthfeel intensity in the RR. In cluster 2, the A treatment was associated with increased citation proportions of *off-flavor* across several time points, which could not be linked to any ‘off-flavor’ attributes in the RR, apart from the bitter taste. The *off-flavor* perceived by cluster 2 might be a metallic taste, which has been associated with ace-K in several studies [19,20,77,78].

4.7. Comment on the Use of Erythritol Sweetener

The naturally sweetened system incorporated erythritol to improve the sensory profile of reb M, as demonstrated by other studies [48]. Recently, the metabolic effects of erythritol consumption were published, showing a concerning relationship with cardiovascular event risk [79]. However, this study used a safe minimal 1.6% concentration of erythritol within maximum limits, which is regarded as safe by EFSA [80]. Due to the lower sweetness potency of erythritol (0.5 times sucrose), it imparted only minimal sweetness to the samples [81]. Consequently, the sensory differences reported for the natural sweetener system primarily originated from reb M.

4.8. Limitations and Perspectives

The primary target for CFM beverages is children and adolescents. In this study, we recruited participants among young student consumers, representing a subset of adolescents, but not the entire target group. Therefore, our findings may not be generalizable to the whole target population.

The number of consumers included in the study is adequate for consumer studies. However, clustering of consumers into subgroups, including two consumer clusters with a relatively small number of consumers and a noise cluster, might have resulted in low statistical power in ANOVA and multiple comparison tests. The noise cluster approach was implemented to exclude atypical consumers who were shown to have higher liking of sucrose-replaced treatments compared to the sucrose treatment. Nevertheless, dividing the TCATA citations into discrete time periods compensated partly for the low number of consumers in the clusters [38].

Defining bitter taste can be challenging for some consumers who confuse it with other taste attributes [82]. Considering the citation frequency of off-flavor being higher for the treatment A in the cluster 2, it is possible that bitter taste perceptions were dumped into the attribute *off-flavor*.

5. Conclusions

Partial sucrose replacement in CFM resulted in a similar sensory profile to the sucrose treatment, regardless of the sweetener system. In contrast, complete replacement of sucrose led to an altered sensory profile collectively associated with bitter taste, mouth-drying sensation and different off-flavors in the Relative-to-Reference Scaling. Considering responses across all consumers, liking was maintained with partial sucrose replacement independent of the sweetener system applied. Decreased liking was associated with the perception of off-flavor with complete replacement in both a natural and a synthetic sweetener system. Clustering on consumer liking showed individual variations towards sucrose replacement depended on the sweetener system applied. In cluster 1, consumers showed decreased

liking for treatments with the natural sweetener system, regardless of the replacement level. In cluster 2, perceptions of bitterness were specifically associated with the synthetic sweetener system, where complete sucrose replacement without affecting liking was not feasible. These findings suggest that partial sucrose replacement can be an effective strategy for achieving sugar reduction without compromising the sensory profile or consumer liking and underscores the importance of considering consumer segments.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/beverages10030054/s1>, Supplementary Figure S1. Violin plots with mean and std. error of liking ratings from the noise cluster ($n = 16$). Treatments are sucrose (S), sucrose and ace-K (S+A), sucrose and reb M (S+R), ace-K (A) and reb M (R). Significant differences between means of the sucrose treatment and sucrose-replaced treatments are indicated with lines above the plot with asterisk: NS = non-significant ($p > 0.05$), ** = $p < 0.01$, and *** = $p < 0.001$.

Author Contributions: Conceptualization, G.B.H.A., C.L.D.C., J.C.C., N.A. and U.K.; data curation, G.B.H.A.; formal analysis, G.B.H.A. and J.C.C.; funding acquisition, D.V.B. and U.K.; investigation, G.B.H.A. and C.L.D.C.; methodology, G.B.H.A., C.L.D.C., J.C.C. and N.A.; project administration, D.V.B. and U.K.; resources, G.B.H.A.; software, G.B.H.A. and J.C.C.; supervision, J.C.C., N.A., D.V.B. and U.K.; validation, G.B.H.A.; visualization, G.B.H.A.; writing—original draft, G.B.H.A.; writing—review and editing, G.B.H.A., J.C.C., N.A., D.V.B. and U.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to the reason that research in sensory properties of foods is exempted from the requirements of ethical approval. Participating in this study did not inflict risks beyond those encountered in normal everyday life.

Informed Consent Statement: Consumers and panelists gave their informed consent before starting the study and were informed that: (1) they were going to taste lactose-free sucrose-replaced CFM; (2) participation was voluntary, and they could withdraw at any time without stating a reason; (3) participation in this study did not inflict risks beyond those encountered in normal everyday life; (4) data collection was completely anonymous.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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Conflicts of Interest: Author John C. Castura was employed by the company Compusense Inc. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Hutchings, S.C.; Low, J.Y.Q.; Keast, R.S.J. Sugar reduction without compromising sensory perception. An impossible dream? *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 2287–2307. [CrossRef]
2. Li, X.E.; Lopetcharat, K.; Drake, M.A. Parents’ and children’s acceptance of skim chocolate milks sweetened by monk fruit and stevia leaf extracts. *J. Food Sci.* **2015**, *80*, S1083–S1092. [CrossRef]
3. Zhao, L.Q.; Tepper, B.J. Perception and acceptance of selected high-intensity sweeteners and blends in model soft drinks by propylthiouracil (PROP) non-tasters and super-tasters. *Food Qual. Prefer.* **2007**, *18*, 531–540. [CrossRef]
4. Andersen, G.H.; Alexi, N.; Sfyra, K.; Byrne, D.V.; Kidmose, U. Temporal check-all-that-apply on the sensory profiling of sucrose-replaced sweetener blends of natural and synthetic origin. *J. Sens. Stud.* **2023**, *38*, e12838. [CrossRef]
5. Haug, A.; Høstmark, A.T.; Harstad, O.M. Bovine milk in human nutrition—A review. *Lipids Health Dis.* **2007**, *6*, 25. [CrossRef] [PubMed]
6. Bailey, R.L.; Fulgoni, V.L.; Cowan, A.E.; Gaine, P.C. Sources of Added Sugars in Young Children, Adolescents, and Adults with Low and High Intakes of Added Sugars. *Nutrients* **2018**, *10*, 102. [CrossRef] [PubMed]

7. Striegel-Moore, R.H.; Thompson, D.; Affenito, S.G.; Franko, D.L.; Obarzanek, E.; Barton, B.A.; Schreiber, G.B.; Daniels, S.R.; Schmidt, M.; Crawford, P.B. Correlates of beverage intake in adolescent girls: The National Heart, Lung, and Blood Institute Growth and Health Study. *J. Pediatr.* **2006**, *148*, 183–187. [\[CrossRef\]](#)
8. Coyle, D.H.; Ndanuko, R.; Singh, S.; Huang, P.; Wu, J.H. Variations in Sugar Content of Flavored Milks and Yogurts: A Cross-Sectional Study across 3 Countries. *Curr. Dev. Nutr.* **2019**, *3*, nzz060. [\[CrossRef\]](#)
9. Mahato, D.K.; Keast, R.; Liem, D.G.; Russell, C.G.; Ciceralo, S.; Gamlath, S. Sugar Reduction in Dairy Food: An Overview with Flavoured Milk as an Example. *Foods* **2020**, *9*, 1400. [\[CrossRef\]](#) [\[PubMed\]](#)
10. Miele, N.A.; Cabisidan, E.K.; Plaza, A.G.; Masi, P.; Cavella, S.; Di Monaco, R. Carbohydrate sweetener reduction in beverages through the use of high potency sweeteners: Trends and new perspectives from a sensory point of view. *Trends Food Sci. Technol.* **2017**, *64*, 87–93. [\[CrossRef\]](#)
11. Oliveira, D.; Antunez, L.; Gimenez, A.; Castura, J.C.; Deliza, R.; Ares, G. Sugar reduction in probiotic chocolate-flavored milk: Impact on dynamic sensory profile and liking. *Food Res. Int.* **2015**, *75*, 148–156. [\[CrossRef\]](#)
12. Oltman, A.E.; Lopetcharat, K.; Bastian, E.; Drake, M.A. Identifying Key Attributes for Protein Beverages. *J. Food Sci.* **2015**, *80*, S1383–S1390. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Saraiva, A.; Carrascosa, C.; Raheem, D.; Ramos, F.; Raposo, A. Natural Sweeteners: The Relevance of Food Naturalness for Consumers, Food Security Aspects, Sustainability and Health Impacts. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6285. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Román, S.; Sánchez-Siles, L.M.; Siegrist, M. The importance of food naturalness for consumers: Results of a systematic review. *Trends Food Sci. Tech.* **2017**, *67*, 44–57. [\[CrossRef\]](#)
15. Brodock, J.L.; Hayes, J.E.; Masterson, T.D.; Hopfer, H. Differences in preferred fat level, sweetener type, and amount of added sugar in chocolate milk in a choice task relate to physical activity and orthorexia. *Appetite* **2021**, *163*, 105214. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Li, X.E.; Lopetcharat, K.; Drake, M. Extrinsic attributes that influence parents' purchase of chocolate milk for their children. *J. Food Sci.* **2014**, *79*, S1407–S1415. [\[CrossRef\]](#)
17. Shindou, T.; Sasaki, Y.; Eguchi, T.; Eguchi, T.; Hagiwara, K.; Ichikawa, T. Identification of erythritol by HPLC and GC-MS and quantitative measurement in pulps of various fruits. *J. Agric. Food Chem.* **1989**, *37*, 1474–1476. [\[CrossRef\]](#)
18. Mora, M.R.; Dando, R. The sensory properties and metabolic impact of natural and synthetic sweeteners. *Compr. Rev. Food Sci. Food Saf.* **2021**, *20*, 1554–1583. [\[CrossRef\]](#)
19. Reyes, M.M.; Castura, J.C.; Hayes, J.E. Characterizing Dynamic Sensory Properties of Nutritive and Nonnutritive Sweeteners with Temporal Check-All-That-Apply. *J. Sens. Stud.* **2017**, *32*, e12270. [\[CrossRef\]](#)
20. Tan, V.W.K.; Wee, M.S.M.; Tomic, O.; Forde, C.G. Temporal sweetness and side tastes profiles of 16 sweeteners using temporal check-all-that-apply (TCATA). *Food Res. Int.* **2019**, *121*, 39–47. [\[CrossRef\]](#)
21. Choi, J.H.; Chung, S.J. Sweetness potency and sweetness synergism of sweeteners in milk and coffee systems. *Food Res. Int.* **2015**, *74*, 168–176. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Gotow, N.; Esumi, S.; Kubota, H.; Kobayakawa, T. Comparison of Temporal Profiles among Sucrose, Sucralose, and Acesulfame Potassium after Swallowing Sweetened Coffee Beverages and Sweetened Water Solutions. *Beverages* **2018**, *4*, 28. [\[CrossRef\]](#)
23. Junge, J.Y.; Mielby, L.A.; Zeng, Y.; Sun, Y.X.; Byrne, D.V.; Castura, J.C.; Kidmose, U. Investigating the temporality of binary taste interactions in blends of sweeteners and citric acid in solution. *J. Sens. Stud.* **2022**, *37*, e12270. [\[CrossRef\]](#)
24. Tan, V.W.K.; Wee, M.S.M.; Tomic, O.; Forde, C.G. Rate-All-That-Apply (RATA) comparison of taste profiles for different sweeteners in black tea, chocolate milk, and natural yogurt. *J. Food Sci.* **2020**, *85*, 486–492. [\[CrossRef\]](#)
25. Pedersen, L.; Bertelsen, A.S.; Byrne, D.V.; Kidmose, U. Sensory Interactions between Sweetness and Fat in a Chocolate Milk Beverage. *Foods* **2023**, *12*, 2711. [\[CrossRef\]](#)
26. Castura, J.C.; Antúnez, L.; Giménez, A.; Ares, G. Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Qual. Prefer.* **2016**, *47*, 79–90. [\[CrossRef\]](#)
27. Harwood, W.S.; Drake, M. Application of temporal penalty analysis for the optimization of sugar reduction in protein beverages. *J. Sens. Stud.* **2021**, *36*, e12644. [\[CrossRef\]](#)
28. Parker, M.N.; Lopetcharat, K.; Drake, M.A. Consumer acceptance of natural sweeteners in protein beverages. *J. Dairy Sci.* **2018**, *101*, 8875–8889. [\[CrossRef\]](#) [\[PubMed\]](#)
29. Bertelsen, A.S.; Mielby, L.A.; Alexi, N.; Byrne, D.V.; Kidmose, U. Sweetness Enhancement by Aromas: Measured by Descriptive Sensory Analysis and Relative to Reference Scaling. *Chem. Senses* **2020**, *45*, 293–301. [\[CrossRef\]](#)
30. Stoer, N.L.; Lawless, H.T. Comparison of Single Product Scaling and Relative-to-Reference Scaling in Sensory Evaluation of Dairy Products. *J. Sens. Stud.* **2007**, *8*, 257–270. [\[CrossRef\]](#)
31. Lawless, H.T.; Heymann, H. Descriptive Analysis. In *Sensory Evaluation of Food*, 2nd ed.; Food Science Text Series; Springer: New York, NY, USA, 2010; pp. 227–257.
32. ISO 8589:2007; Sensory Analysis—General Guidance for the Design of Test Rooms. ISO: Geneva, Switzerland, 2007. Available online: <https://www.iso.org/standard/36385.html> (accessed on 19 May 2024).
33. ISO 8586:2012; Sensory analysis—General Guidelines for the Selection, Training and Monitoring of Selected Assessors and Expert Sensory Assessors. ISO: Geneva, Switzerland, 2012. Available online: <https://www.iso.org/standard/45352.html> (accessed on 19 May 2024).

34. Ares, G.; Castura, J.C.; Antúnez, L.; Vidal, L.; Giménez, A.; Coste, B.; Picallo, A.; Beresford, M.K.; Chheang, S.L.; Jaeger, S.R. Comparison of two TCATA variants for dynamic sensory characterization of food products. *Food Qual. Prefer.* **2016**, *54*, 160–172. [CrossRef]
35. Visalli, M.; Mahieu, B.; Thomas, A.; Schlich, P. Concurrent vs. retrospective temporal data collection: Attack-evolution-finish as a simplification of Temporal Dominance of Sensations? *Food Qual. Prefer.* **2020**, *85*, 103956. [CrossRef]
36. Dinnella, C.; Masi, C.; Naes, T.; Monteleone, E. A new approach in TDS data analysis: A case study on sweetened coffee. *Food Qual. Prefer.* **2013**, *30*, 33–46. [CrossRef]
37. McMahon, K.M.; Culver, C.; Castura, J.C.; Ross, C.F. Perception of carbonation in sparkling wines using descriptive analysis (DA) and temporal check-all-that-apply (TCATA). *Food Qual. Prefer.* **2017**, *59*, 14–26. [CrossRef]
38. Meyners, M.; Hasted, A. On the applicability of ANOVA models for CATA data. *Food Qual. Prefer.* **2021**, *92*, 104219. [CrossRef]
39. Meyners, M.; Hasted, A. On the choice of appropriate models for CATA data—A further reply to Bi and Kuesten. *Food Qual. Prefer.* **2023**, *106*, 104818. [CrossRef]
40. Vigneau, E.; Chen, M.K.; Qannari, E.M. ClustVarLV: An R Package for the Clustering of Variables Around Latent Variables. *R J.* **2015**, *7*, 134–148. [CrossRef]
41. Vigneau, E.; Qannari, E.M.; Navez, B.; Cottet, V. Segmentation of consumers in preference studies while setting aside atypical or irrelevant consumers. *Food Qual. Prefer.* **2016**, *47*, 54–63. [CrossRef]
42. Wickham, H.; Averick, M.; Bryan, J.; Chang, W.; McGowan, L.; François, R.; Grolemund, G.; Hayes, A.; Henry, L.; Hester, J.; et al. Welcome to the Tidyverse. *J. Open Source Softw.* **2019**, *4*, 1686. [CrossRef]
43. Kuznetsova, A.; Brockhoff, P.B.; Christensen, R.H.B. lmerTest Package: Tests in Linear Mixed Effects Models. *J. Stat. Softw.* **2017**, *82*, 1–26. [CrossRef]
44. Lenth, R.V. emmeans: Estimated Marginal Means, Aka Least-Squares Means. 2022. Available online: <https://cran.r-project.org/web/packages/emmeans/emmeans.pdf> (accessed on 19 May 2024).
45. Schiffman, S.S.; Booth, B.J.; Losee, M.L.; Pecore, S.D.; Warwick, Z.S. Bitterness of sweeteners as a function of concentration. *Brain Res. Bull.* **1995**, *36*, 505–513. [CrossRef] [PubMed]
46. Kim, H.-K.; Lee, H.; Shin, J.Y. Sensory Properties and Consumer Acceptability of Coffee Drinks Contained Sucralose and Acesulfame-K. *Korean Soc. Food Sci. Technol.* **2007**, *39*, 527–533.
47. Mora, M.; Wijaya, F.; Jiang, G.; Gibney, P.; Dando, R. Sensory profiling of natural sweeteners and sucrose-sweetener binary mixtures. *J. Food Sci.* **2023**, *88*, 2984–2995. [CrossRef] [PubMed]
48. Prakash, I.; Markosyan, A.; Bunders, C. Development of Next Generation Stevia Sweetener: Rebaudioside M. *Foods* **2014**, *3*, 162–175. [CrossRef] [PubMed]
49. Schiffman, S.S.; Gatlin, L.A.; Sattely-Miller, E.A.; Graham, B.G.; Heiman, S.A.; Stagner, W.C.; Erickson, R.P. The effect of sweeteners on bitter taste in young and elderly subjects. *Brain Res. Bull.* **1994**, *35*, 189–204. [CrossRef] [PubMed]
50. Kim, Y.H.; Hong, J.H. Effects of aroma-taste interaction on the sensory attributes of rebaudiosides in soymilk and milk. *J. Sci. Food Agric.* **2023**, *103*, 7445–7454. [CrossRef]
51. Bertelsen, A.S.; Mielby, L.A.; Alexi, N.; Byrne, D.V.; Kidmose, U. Individual Differences in Sweetness Ratings and Cross-Modal Aroma-Taste Interactions. *Foods* **2020**, *9*, 146. [CrossRef] [PubMed]
52. Bertelsen, A.S.; Zeng, Y.; Mielby, L.A.; Sun, Y.-X.; Byrne, D.V.; Kidmose, U. Cross-modal Effect of Vanilla Aroma on Sweetness of Different Sweeteners among Chinese and Danish Consumers. *Food Qual. Prefer.* **2021**, *87*, 104036. [CrossRef]
53. Sousa Lima, R.; Cazelatto de Medeiros, A.; Andre Bolini, H.M. Sucrose replacement: A sensory profile and time-intensity analysis of a tamarind functional beverage with artificial and natural non-nutritive sweeteners. *J. Sci. Food Agric.* **2021**, *101*, 593–602. [CrossRef]
54. Cadena, R.S.; Cruz, A.G.; Netto, R.R.; Castro, W.F.; Faria, J.D.F.; Bolini, H.M.A. Sensory profile and physicochemical characteristics of mango nectar sweetened with high intensity sweeteners throughout storage time. *Food Res. Int.* **2013**, *54*, 1670–1679. [CrossRef]
55. Reis, F.; Alcaire, F.; Deliza, R.; Ares, G. The role of information on consumer sensory, hedonic and wellbeing perception of sugar-reduced products: Case study with orange/pomegranate juice. *Food Qual. Prefer.* **2017**, *62*, 227–236. [CrossRef]
56. Yang, Q.; Kraft, M.; Shen, Y.C.; MacFie, H.; Ford, R. Sweet Liking Status and PROP Taster Status impact emotional response to sweetened beverage. *Food Qual. Prefer.* **2019**, *75*, 133–144. [CrossRef]
57. Muenprasitvej, N.; Tao, R.; Nardone, S.J.; Cho, S. The Effect of Steviol Glycosides on Sensory Properties and Acceptability of Ice Cream. *Foods* **2022**, *11*, 1745. [CrossRef]
58. Honorio, A.R.; Soares, A.F.; de Lima, D.C.N.; Tribst, A.A.L. Passion fruit nectar sweetened with stevia and sucralose: Is perception affected by the regular consumption of sweeteners or diabetes? *Int. J. Gastron. Food Sci.* **2021**, *25*, 100404. [CrossRef]
59. Rocha, I.F.; Bolini, H.M. Passion fruit juice with different sweeteners: Sensory profile by descriptive analysis and acceptance. *Food Sci. Nutr.* **2015**, *3*, 129–139. [CrossRef] [PubMed]
60. Mahato, D.K.; Keast, R.; Liem, D.G.; Russell, C.G.; Cicerale, S.; Gamlath, S. Optimisation of natural sweeteners for sugar reduction in chocolate flavoured milk and their impact on sensory attributes. *Int. Dairy J.* **2021**, *115*, 104922. [CrossRef]
61. Lee, S.H.; Choe, S.Y.; Seo, G.G.; Hong, J.H. Can “Functional Sweetener” Context Increase Liking for Cookies Formulated with Alternative Sweeteners? *Foods* **2021**, *10*, 361. [CrossRef] [PubMed]
62. Leksrisonpong, P.P.; Lopetcharat, K.; Guthrie, B.; Drake, M.A. Preference mapping of lemon lime carbonated beverages with regular and diet beverage consumers. *J. Food Sci.* **2013**, *78*, S320–S328. [CrossRef] [PubMed]

63. Markey, O.; Lovegrove, J.A.; Methven, L. Sensory profiles and consumer acceptability of a range of sugar-reduced products on the UK market. *Food Res. Int.* **2015**, *72*, 133–139. [[CrossRef](#)]
64. Jaeger, S.R.; Chheang, S.L.; Jin, D.; Ryan, G.S.; Ares, G. How do CATA questions work? Relationship between likelihood of selecting a term and perceived attribute intensity. *J. Sens. Stud.* **2023**, *38*, e12833. [[CrossRef](#)]
65. DuBois, G.E.; Prakash, I. Non-caloric sweeteners, sweetness modulators, and sweetener enhancers. *Annu. Rev. Food Sci. Technol.* **2012**, *3*, 353–380. [[CrossRef](#)]
66. Ayya, N.; Lawless, H.T. Quantitative and Qualitative Evaluation of High-Intensity Sweeteners and Sweetener Mixtures. *Chem. Senses* **1992**, *17*, 245–259. [[CrossRef](#)]
67. Horne, J.; Lawless, H.T.; Speirs, W.; Sposato, D. Bitter taste of saccharin and acesulfame-K. *Chem. Senses* **2002**, *27*, 31–38. [[CrossRef](#)] [[PubMed](#)]
68. Kamerud, J.K.; Delwiche, J.F. Individual differences in perceived bitterness predict liking of sweeteners. *Chem. Senses* **2007**, *32*, 803–810. [[CrossRef](#)]
69. Allen, A.L.; McGeary, J.E.; Hayes, J.E. Rebaudioside A and Rebaudioside D bitterness do not covary with Acesulfame K bitterness or polymorphisms in TAS2R9 and TAS2R31. *Chemosens. Percept.* **2013**, *6*, 109–117. [[CrossRef](#)]
70. Bobowski, N.; Reed, D.R.; Mennella, J.A. Variation in the TAS2R31 bitter taste receptor gene relates to liking for the nonnutritive sweetener Acesulfame-K among children and adults. *Sci. Rep.* **2016**, *6*, 39135. [[CrossRef](#)] [[PubMed](#)]
71. Allen, A.L.; McGeary, J.E.; Knopik, V.S.; Hayes, J.E. Bitterness of the non-nutritive sweetener acesulfame potassium varies with polymorphisms in TAS2R9 and TAS2R31. *Chem. Senses* **2013**, *38*, 379–389. [[CrossRef](#)] [[PubMed](#)]
72. Hopfer, H.; Riak, A.C.; Roberts, R.F.; Hayes, J.E.; Ziegler, G.R. Synergistic and antagonistic ingredient interactions as a sugar reduction strategy in chocolate milk. *J. Sens. Stud.* **2022**, *37*. [[CrossRef](#)]
73. Li, Y.; Ahuja, J.; Nguyen, Q.; Pehrsson, P. Top Sweeteners in Top Contributors of Commercially Processed Foods With Added Sugars in the U.S.: Application of the IngID Program. *Curr. Dev. Nutr.* **2021**, *5*, 560. [[CrossRef](#)]
74. Jaeger, S.; Chheang, S.L.; Jin, D.; Roigard, C.; Ares, G. Check-all-that-apply (CATA) questions: Sensory term citation frequency reflects rated term intensity and applicability. *Food Qual. Prefer.* **2020**, *86*, 103986. [[CrossRef](#)]
75. Alexi, N.; Nanou, E.; Lazo, O.; Guerrero, L.; Grigorakis, K.; Byrne, D.V. Check-All-That-Apply (CATA) with semi-trained assessors: Sensory profiles closer to descriptive analysis or consumer elicited data? *Food Qual. Prefer.* **2018**, *64*, 11–20. [[CrossRef](#)]
76. Moussaoui, K.A.; Varela, P. Exploring consumer product profiling techniques and their linkage to a quantitative descriptive analysis. *Food Qual. Prefer.* **2010**, *21*, 1088–1099. [[CrossRef](#)]
77. Schiffman, S.S.; Crofton, V.A.; Beeker, T.G. Sensory evaluation of soft drinks with various sweeteners. *Physiol. Behav.* **1985**, *34*, 369–377. [[CrossRef](#)] [[PubMed](#)]
78. Riera, C.E.; Vogel, H.; Simon, S.A.; Coutre, J.I. Artificial sweeteners and salts producing a metallic taste sensation activate TRPV1 receptors. *Am. J. Physiol.-Regul. Integr. Comp. Physiol.* **2007**, *293*, R626–R634. [[CrossRef](#)] [[PubMed](#)]
79. Witkowski, M.; Nemet, I.; Alamri, H.; Wilcox, J.; Gupta, N.; Nimer, N.; Haghikia, A.; Li, X.S.; Wu, Y.; Saha, P.P.; et al. The artificial sweetener erythritol and cardiovascular event risk. *Nat. Med.* **2023**, *29*, 710–718. [[CrossRef](#)] [[PubMed](#)]
80. EFSA. Scientific Opinion on the safety of the proposed extension of use of erythritol (E 968) as a food additive. *EFSA J.* **2015**, *13*, 4033. [[CrossRef](#)]
81. Tiefenbacher, K.F. Technology of Main Ingredients—Sweeteners and Lipids. In *Wafer and Waffle*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 123–225.
82. O'Mahony, M.; Goldenberg, M.; Stedmon, J.; Alford, J. Confusion in the use of the taste adjectives 'sour' and 'bitter'. *Chem. Senses* **1979**, *4*, 301–318. [[CrossRef](#)]

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