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Three independent measures of sweet taste liking have weak and inconsistent associations with sugar and sweet food intake - insights from the sweet tooth study

Eva M. Čad[a], Merel van der Kruijssen[a], Claudia S. Tang[b], Leoné Pretorius[b], Hanne B.T. de Jong[a], Monica Mars[a,*], Katherine M. Appleton[b], Kees de Graaf[a]

[a] Division of Human Nutrition and Health, Wageningen University and Research, Wageningen, the Netherlands
[b] Department of Psychology, Faculty of Science and Technology, Bournemouth University, Bournemouth, United Kingdom

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ABSTRACT

Authoritative public health agencies, like the WHO, recommend reducing dietary sweetness to lower sweet liking, and thereby indirectly lowering sugar and energy intake. However, data on an association between sweetness liking and sugar/sweet food intake are inconsistent. Moreover, sweetness liking can be measured in various ways, and the agreement between methods is unclear. Baseline data from the Sweet Tooth study (n = 178) were used to evaluate the agreement between three different measures of sweetness liking and their association with sugar and sweet food intake. Sweetness liking was assed by: 1) psychohedonic sweetness functions, 2) sweet liker phenotype, and 3) self-reported sweet / fat-sweet preference. Sugar and sweet food intake were assessed via 24-h recall and a FFQ assessing the consumption of food groups based on taste (TasteFFQ). On a group level, the three sweetness liking measures showed similar results; sweet liker phenotype showed higher liking of high sweetness levels ($F_{(2,175)} = 27.9$, $p < .001$), and higher preference for sweet and fat-sweet foods (sweet: $\chi^2_{(2)} = 16.2$, p < .001, sweet-fat: $\chi^2_{(2)} = 24.8$;p < .001). Self-reported preferences for sweet foods were associated with intake of simple sugars ($\chi^2_{(1)} = 6.10$, $p = .014$), energy ($\chi^2_{(1)} = 5.82$, $p = .016$), and sweet foods ($\chi^2_{(1)} = 5.05$, $p = .025$). Neither the psychohedonic functions, sweet liker phenotype nor self-reported fat-sweet preferences were associated with sugar and/or sweet food intake (all $p > .05$). These findings suggest that, while sweetness preferences can be measured using different approaches, high sweetness liking has only a limited relationship with actual sugar and sweet food intake. These findings challenge the assumption that preferences for sweet tastes drive high intakes of sweet foods and sugars.

Ethical approval for the involvement of human subjects in this study was granted by METC-WU, ABR nr. NL72134, 10/05/20.

1. Introduction

People love sweetness; the human desire for sugar induced sweetness has shaped the socio-economic developments of societies from the Middle Ages until the present day (Mela & Risso, 2024; Mintz, 1985). In 2024, sugar consumption across the world was equal to 179 million metric tons (US Department of Agriculture, 2024), which equates to an average of 60 g sugar/person/day. Foods that contribute to this number are, for example, sugar-sweetened beverages, sweetened dairy, and confectionary. Across the world, the intake of sugar - mono- and disaccharides contributes up to about 10–20 % of daily energy intake (Walton et al., 2023). Nowadays, people also consume low energy sweeteners, next to sugars, to give sweetness to their diet, mostly in the form of sweet tasting drinks (Martyn et al., 2018). Although exact sweetener intake is difficult to assess, the global revenue for artificial sweeteners is projected to increase by 40.4 % between 2024 and 2029,

Abbreviations: BMI, Body mass index; LMM, Linear Mixed Model; NSS, Non-sugar sweeteners; PrefQuest-Fat-Sweet, Liking for Fat and Sweet foods assessed with PrefQuest; PrefQuest-Sweet, Liking for Sweet foods assessed with PrefQuest; RoS, Ranking on a Scale; Sweet-Liker-Phenotype, Sweet Liker Phenotype; Sweet-Food-Liking, Liking score assessed by tasting six sweet foods; Sweet-Food-Preferred-Concentration, Preferred sweetness concentration level assessed by tasting six sweet foods; VAS, Visual Analogue Scale.

* Corresponding author at: Stippeneng 4, Nl-6708 WE Wageningen, the Netherlands.
E-mail address: monica.mars@wur.nl (M. Mars).

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highlighting their growing use as sugar substitutes (Statista, 2024).

Recently, some nutritionists have expressed their concern about the global sweetening of the diet (Popkin & Hawkes, 2016). Also, the WHO argues that we should reduce the sweetness of the diet altogether, starting early in life, to improve health (World Healh Organization, 2023). One of the implicit assumptions behind this recommendation is that a reduction in sweet liking would lead to a lower sugar and energy intake (Appleton et al., 2018). However, the relationship between sweet taste liking and sweet food and sugar intake is not straightforward (de Graaf et al., 2005; Mattes, 2024). For example, Papantoni et al. (2021) did not find any relationship between the liking for milkshakes high in sweetness and the percentage of energy coming from sugar in the diets of 105 healthy weight US adolescents. Garneau et al. (2018) measured the liking response of 650 adults to a variety of aqueous sugar solutions varying from 0 to 13.7 *w/v*. They observed no significant differences in beverage intake between the adults who expressed a lower or higher liking for higher sugar concentrations. Also, Armitage et al. (2023) found no consistent relationships between sweetness liker phenotype and dietary sugar intake. However, a large-scale epidemiological study where sweetness liking was measured with a questionnaire did find a positive association between sweetness liking and the intakes of various sweet foods (Lampure et al., 2016). Thus, the evidence supporting that higher liking for sweetness is associated with higher sugar intakes is not consistent. A systematic review noted that methodological differences in how sweetness liking and dietary intake are measured, contribute to these inconsistencies (Tan & Tucker, 2019).

Our "love" for sweetness has been measured by asking how people appreciate the sensation of sweetness while tasting it in the mouth, i.e. the liking of sweet taste, or by measuring the preference of one level of sweetness/other taste over another level/taste. This can be done through actual tasting of sweet foods (Čad, Tang, Mars, et al., 2023), through tasing sweet water solutions (Iatridi et al., 2019a), through the choice response to pictures of foods with different sweetness levels (e.g. the Leeds food Preference Questionnaire; Finlayson et al., 2007), or through the response to questions about the liking/preferences for certain foods, e.g., the Taste and Health questionnaire (Roininen et al., 2001) or the PrefQuest questionnaire (Deglaire et al., 2012). For the purpose of this study, we compared three methods that used extensive development and validation steps to measure sweet taste liking/preference. The first one was a measure of a generalized liking/preference for sweet taste across a number of different foods that vary in sweetness intensity levels (Čad, Tang, Mars, et al., 2023). The second one characterises people based on a so-called sweet-liker phenotype (Armitage, Iatridi and Yeomans, 2021). This method, which was proposed after a methodological review of the existing literature (Iatridi et al., 2019b), uses data-base cut offs to classify individuals as being sweet dislikers, moderate sweet-likers, or sweet likers based on a single liking rating of a 1 M sucrose in water solution (Iatridi et al., 2019a). The third measure was Sweet taste liking as assessed by a questionnaire tested among tens of thousands of French people (PrefQuest; Deglaire et al., 2012). PrefQuest is a questionnaire that measures sweetness liking through a 21 item self-report scale, including four types of items, 1) liking for sweet foods on a 9-point hedonic scale, 2) preferred level of sweet seasonings, 3) preferred sweetness in drinks (e.g. sweetened or unsweetened coffee/tea) and 4) dietary behaviour with sweet foods (Deglaire et al., 2012).

A systematic review on sweetness liking and intake by Tan and Tucker (2019) concludes that "future work should explore obtaining more than one taste measurement before comparing results to longer-term dietary assessments". Thus, the objective of this study was to assess the agreement of three sweetness liking measures and investigate if they relate to sweet food and sugar intake.

2. Methods

2.1. Subjects and study design

This study is a cross-sectional analysis using baseline data from the 'Sweet Tooth Study', a randomized controlled trial with 6-months of partial food provision investigating the effect of low, regular and high dietary sweetness exposure on sweetness liking. The design and methodology have been described in detail previously (Čad, Tang, de Jong, et al., 2023). The trial adhered to the Helsinki Declaration and received approval from the Medical Ethical Committee of Wageningen University and Research (ABR no. NL72134, October 5, 2020). The trial was pre-registered at ClinicalTrials.gov (ID no. NCT04497974), with all participants providing oral and written informed consent and receiving financial compensation.

Baseline measurements of the study were done during a 3 year period, from October 2020 to September 2023. Participants were recruited from Wageningen and surroundings via a pre-existing participant database, internet-based advertisements, printed media and flyer distribution. Participants were eligible if they were aged 18–65 years, had a BMI of 18.5–30 kg/m^2, and were in good general health. Exclusion criteria included abnormal fasting blood glucose, as assessed at a screening visit with a finger prick, self-reported diagnosis of diabetes or any other metabolic disorder, self-reported recent significant weight change, self-reported eating or sensory disorders, medication affecting taste perception or glucose metabolism, food allergies or intolerances, pregnancy, lactation, excessive alcohol (more than 14 glasses of alcohol per week) or any drug use, and being affiliated with the division of Human Nutrition and Health at Wageningen University. More detailed eligibility criteria are described in the original study protocol publication by Čad, Tang, de Jong, et al. (2023).

2.2. Measures and procedures

2.2.1. Participant characteristics

Participants self-reported their sex, age, education level, smoking status, and other demographic information using the general inclusion questionnaire. BMI was calculated using the formula: BMI = weight (kg) / height (m)^2. Weight and height were measured with participants wearing light clothing and no footwear. Height was measured to the nearest 0.1 cm using a stadiometer (SECA, Germany). Weight was measured twice with a calibrated digital weighing scale (SECA, Germany) to the nearest 0.1 kg, and the average of the two measurements was recorded in the dataset. Weight measurements were taken early in the morning, in a fasted state.

2.2.2. Sweetness liking measures

2.2.2.1. Psychohedonic sweetness functions. Psychohedonic sweetness functions were gained through sensory tests involving six different sweet foods: three familiar and three unfamiliar. These foods varied in five sweetness concentration levels, resulting in a total of 30 samples. Table 1 shows the test foods and their intensity levels which were extensively tested during their development. Detailed descriptions of the test foods and the steps for their development are described in Čad, Tang, Mars, et al. (2023).

Participants evaluated the test foods on liking and preference using Ranking on a Scale (RoS) methodology (Sung & Wu, 2018). This method allows participants to directly compare the varying intensity levels of the samples. It also allows for ties when two or more samples were equally liked. Participants were instructed to taste and swallow a mouthful of each sample and rate their liking using a single 100-unit Visual Analogue Scale (VAS). The VAS was anchored on the left side with 'dislike extremely', 'like extremely' at the right side, and 'neither like nor dislike' in the middle. Scores were digitally recorded using

Table 1
Test sweet foods and sweetener concentration levels, for each level, for each level of sweetness.

	Test food	Food form	Serving size	Serving temperature	Sweetener concentration (sucrose * + non-nutritive sweetener[†]) (% by weight)				
					L-2	**L-1**	**L-0**	**L+1**	**L+2**
Familiar	**Strawberry flavoured lemonade**	Liquid	20 mL	22 °C	0.0 + 0.0	1.3 + 0.0	3.1 + 0.0	8.6 + 0.0	15.1 + 0.0
	Chocolate flavoured custard	Semi-Solid	15 g	5 °C	3.4 + 0.0	6.6 + 0.0	12.4 + 0.0	17.6 + 0.0	26.3 + 0.0
	Plain Cake	Solid	20 g	22 °C	9.1 + 0.0	16.7 + 0.0	18.2 + 0.9	17.6 + 4.2	16.9 + 8.2
Unfamiliar	**Watermelon flavoured lemonade**	Liquid	20 mL	22 °C	0.0 + 0.0	1.3 + 0.0	3.1 + 0.0	8.6 + 0.0	15.1 + 0.0
	Elderflower flavoured custard	Semi-Solid	15 g	5 °C	3.6 + 0.0	7.1 + 0.0	13.2 + 0.0	18.4 + 0.6	21.9 + 5.9
	Tamarind flavoured cake	Solid	20 g	22 °C	9.1 + 0.0	16.6 + 0.0	18.1 + 0.9	17.5 + 4.2	16.8 + 8.1

[†] Liquid sweetener based on cyclamate and saccharin (Rio Zoetstof, Sweet Life AG, Switzerland). Note: Recipes for test foods preparation are available in Čad, Tang, Mars, et al. (2023).
* Sucrose, Kristal suiker, Van Gilse, the Netherlands.

EyeQuestion® (version 6.0.5, EyeQuestion Software, the Netherlands). Participants evaluated the samples in sensory booths under normal lighting and odour-free conditions. The order of sample presentation was randomized, with stimuli labelled using three-digit random codes and provided in standardized amounts either cold (5 °C) or at room temperature (22 °C) in translucent 30 mL cups or on small aluminium trays. Participants were instructed to rinse their palate between samples.

The RoS method enabled the extraction of both liking and ranking scores. Liking scores were provided by participants as a response to the stimuli, using a scale from 0 to 100, where a higher score indicates greater liking. Furthermore, we determined participants' preferred concentration by extracting the sample number (1–5) of the foods that were ranked as most preferred, i.e. at the optimal sweetness level. We calculated the 'average preferred concentration' by averaging the sample numbers (1 to 5) across all test foods. A higher average score indicated a preference for samples with a higher sweetness concentration, whereas a lower score indicated a preference for samples with a lower sweetness concentration. The outcome measures are referred to as Sweet-Food-Liking, for liking score and Sweet-Food-Preferred-Concentration for 'average preferred concentration' in the following sections.

2.2.2.2. Sweet liker phenotype. Sweet liker phenotype status was determined using a 1.0 M sucrose solution (342.3 g/L), prepared by dissolving food-grade sugar in water, according to the procedure described by Iatridi et al. (2019a). Participants received a 10 mL taste stimulus at room temperature and were instructed to taste and swallow it prior to evaluating their liking. Responses were collected using a 100-unit horizontal line scale, anchored by 'dislike extremely' on one end and 'like extremely' on the other. Responses were collected using EyeQuestion® (version 6.0.5, EyeQuestion Software, the Netherlands). Based on their liking score, participants were classified into one of three sweet liker phenotypes, using the following cut-off values: Sweet Dislikers (score ≤ 35), Moderate Sweet Likers (score 36–64) and Sweet Likers (score ≥ 65) (Iatridi et al., 2019a). The Sweet Liker Phenotype measure is referred to as Sweet-Liker-Phenotype in the following sections.

2.2.2.3. General Liking for sweet and sweet fat foods. General liking for sweet and fat-sweet foods was assessed with the PrefQuest questionnaire (Deglaire et al., 2012), which was adapted for Dutch participants. The questionnaire was first translated into Dutch (in'to Languages, Wageningen, The Netherlands). Next, two native Dutch researchers and two native Dutch dietitians reviewed and identified French foods that are not commonly eaten in the Netherlands, which were then excluded. These excluded French foods were replaced with typical Dutch foods from the same taste and food categories, using data from the Dutch Taste Database (Mars et al., 2020) and the Dutch Food Consumption Survey (2012–2016) (Van Rossum et al., 2011). For example, 'le paris-brest', a traditional French pastry made from praline cream and almond flakes from the Fat and Sweet category, was substituted with 'slagroomsoesje', a puff pastry, typically filled with whipped cream categorized under Sweet and Fat (van Langeveld et al., 2018). Additionally, images were adjusted to align with Dutch dietary habits; for instance, we replaced the French bread with a slice of bread typical for the Dutch context. The adapted Questionnaire can be found in supplementary materials (S1_NLPrefQuest). The questionnaire was administered online via Qualtrics online platform (Qualtrics, Provo, UT).

The PrefQuest questionnaire consists of four sections covering: (1) Liking for foods: rated on a nine-point scale with anchors 'I don't like it at all' and 'I like it very much'; (2) Preferences for seasoning levels: rated on either a six-point scale with pictures or a five-point scale without pictures, with anchors such as 'not sweet at all' and 'very sweet'; (3) Preferred drinks: up to three preferred drinks were from a list of six options; and (4) Dietary behaviour questions: answered on a five-point frequency scale from 'never' to 'always' (e.g., 'Do you ever have to salt your dish before you have tasted it?') or a nine-point scale from 'not at all' to 'very much' (e.g., 'Do you mind eating this butterless sandwich?').

Overall, the questionnaire includes 83 items categorized into the sub-subscales: liking for salty (11 items), sweet (21 items), fat & salt (31 items), and fat & sweet (20 items) items. Since liking for the items was assessed on different scales, that is a 5-, 6- and 9-point scale, the responses were first linearly transformed to result in values ranging from 0 to 10 as described by Deglaire et al. (2015). After that, liking scores for each sub-scale were computed by averaging the ratings of the corresponding items, and these scores were subsequently averaged for each taste modality. For the aim of this paper, we only used scores of subscales sweet and fat &sweet. They are referred to as PrefQuest-Sweet and PrefQuest-Fat-Sweet in the following sections.

2.2.3. Sweet food and sugar intake

Sweet food and sugar intake was assessed using a 24-h recall and a questionnaire - TasteFFQ. Participants completed a web-based 24-h recall using the software Tool Compl-Eat™ (www.compleat.nl, Wageningen University, the Netherlands) (Meijboom et al., 2017). They reported their intake from the previous day, starting from waking up until the next morning. The Compl-Eat™ tool guided participants to report all foods and drinks consumed, allowing them to select foods and standard recipes commonly used by the Dutch population. At the end of the recall, Compl-Eat™ reminded participants to include often forgotten items such as sugar in coffee, snacks, fruit, and cooking fat. Trained dietitians checked all the web-based 24-h recalls for completeness and unusual portion sizes, and processed any notes made by the participants.

From the recall data, total energy intake (kcal), intake of mono- and di-saccharides (g), energy intake (en%) from sweet foods and weight intake (w%) of sweet foods were calculated. For the nutrient calculations the most recent Dutch food composition table (RIVM, 2023) was used. To assess sweet food intake, sweet taste intensity values were assigned to the consumed food items using the Taste Database (Mars et al., 2020). See van Langeveld et al. (2018) on how the Taste Database was developed. This assignment was performed in several steps (shown in the flowchart in Supplementary materials, Fig. S1). Initially, reported consumed foods were merged with the Taste Database based on their NEVO food code (RIVM, 2019, 2023). For foods not in the database, we either assigned taste intensity values based on the best match (e.g., full-fat Greek yogurt was assigned taste values of regular full-fat yogurt) or we estimated mean taste intensity values based on corresponding food groups, as described by van Langeveld et al. (2018).

After this, hierarchical cluster analysis was applied on the foods' mean taste intensity values, in order to form groups with similar tasting foods. The number of clusters was determined using Ward's method, resulting in seven clusters, accounting for 73 % of the explained variance. The identified taste clusters were labelled as: 'neutral', 'sweet & sour', 'bitter', 'sour & fat', 'fat, salt & umami', 'sweet & fat', and 'fat'. Mean taste intensity values of the clusters can be found in Supplementary materials, Table S1. Food items in the 'sour & sweet' taste cluster were primarily fruits, whereas the 'sweet & fat' cluster included candy, desserts, sweet spreads, pastries, and cookies. Both the 'sour & sweet' and 'sweet & fat' clusters were combined into a single 'sweet' cluster. Based on this, we calculated both the amount of energy (en%), and the intake (w%) of sweet foods consumed as a measure of dietary sweet food intake. This approach allowed us to also account for sweet-tasting foods that contribute little or no calories, such as sodas with non-sugar sweeteners (NNS), which still contribute to sweet taste within the diet.

Long-term intake of sweet foods was assessed with a TasteFFQ which assesses relative taste exposure through the measurement of specific food items based on frequency, amount and type of food consumed, over the past month. The main purpose of the TasteFFQ is to assess habitual dietary taste patterns in adults, in terms of intake, for example, of sweet tasting foods rather than quantifying their intake. The TasteFFQ includes questions about the intake frequency and amount of 162 food items. These items are categorized into 7 Fat, 35 Neutral, 25 Sweet & Sour, 56 Salt Umami & Fat, 31 Sweet & Fat, and 8 Bitter tasting food items (Čad, Tang, de Jong, et al., 2023). From the TasteFFQ data, we calculated the intake of sweet foods, as total reported percentage compared to total intake (based on estimated weight consumed (frequency x average portion amount) by combining the consumption weight of items classified as 'sweet & fat' and 'sweet & sour'.

2.3. Statistical analysis

Data were analysed using R (version 4.4.0). Continuous variables were reported as mean (M) and standard deviation (s.d.) or 95%-confidence intervals (95%-CI), while categorical variables were summarized using counts (n) and percentages (%). In all analyses, a p-value of less than 0.05 was considered statistically significant.

Before performing statistical analyses, to investigate associations between different sweetness liking measures and their relation to sugar and sweet food intake, participants were categorized into groups for each sweetness liking outcome measure based on tertiles, predefined cutoffs (Sweet-Liker-Phenotype groups), or median splits. We opted to use groups rather than raw values to simplify comparisons between sweet liking measures and to facilitate a clearer interpretation of the relationship between liking and intake. Using tertiles, participants were categorized into low ($n = 59$, M = 33), medium ($n = 58$, M = 44), and high ($n = 61$, M = 55) groups based on their mean Sweet-Food-Liking score. Based on Sweet-Food-Preferred-Concentration scores, using tertiles, participants were divided into low ($n = 64$, M = 2.5), medium ($n = 60$, M = 3.2), and high ($n = 54$, M = 3.9) groups. The Sweet-Liker-Phenotype groups, based on predefined cut-offs from Iatridi et al. (2019b), included Sweet Dislikers ($n = 62$, M = 16), Moderate Sweet Likers (n = 58, M = 51), and Sweet Likers (n = 58, M = 79). Finally, participants were divided, using median split, into low and high groups based on PrefQuest-Sweet and PrefQuest-Fat-Sweet scores (low PrefQuest-Sweet: $n = 110$, M = 2.9; high PrefQuest-Sweet: $n = 68$, M = 4.1; low PrefQuest-Fat-Sweet: $n = 114$, M = 3.83; high PrefQuest-Fat-Sweet: n = 64, M = 5.42).

Initially exploratory analysis was performed for the psychohedonic sweetness function measure. Linear mixed-effects model (LMM) was used to explore the effects of sweetness concentration levels on liking (Sweet-Food-Liking), with concentration level as a fixed factor, and participant as a random factor (lmer function). To investigate associations between different measures, several statistical models were applied. LMM (lmer function, lme4 package) was used to compare Sweet-Food-Liking scores across Sweet-Liker-Phenotype groups, accounting for multiple liking scores per participant across several concentration levels. The model included Sweet-Liker-Phenotype and concentration level as fixed effects and participant as a random effect. Assumption checks for normality (QQ plot) and homoscedasticity (residual vs. fitted plot) indicated no violations for LMM. Differences in Sweet-Food-Preferred-Concentration scores between Sweet-Liker-Phenotype groups were analysed using ANOVA (stats (Base R)). Homogeneity of variance was confirmed by Levene's tests, and normality of residuals was assessed via QQ plots and Shapiro-Wilk test (car package). Non-parametric Kruskal-Wallis tests were employed to assess differences in PrefQuest responses between the Sweet-Food-Liking, Sweet-Food-Preferred-Concentration, and Sweet-Liker-Phenotype groups, as the residuals were not normally distributed, violating the assumptions for ANOVA. Similarly, Kruskal-Wallis tests were used to explore associations between liking measures and the intake of sugar and sweet foods, since the assumption of normality was violated for mono- and disaccharides intake, energy intake from sweet foods, and intake of sweet foods in weight from both 24 h recall and TasteFFQ. In cases of significant main or interaction effects, post-hoc pairwise tests were conducted with Bonferroni adjustments to control for multiple comparisons. For non-parametric tests, pairwise Wilcoxon tests with Bonferroni corrections were applied. Estimated marginal means with 95 % confidence intervals are reported.

3. Results

3.1. Participants characteristics

Out of 180 participants who completed both sensory tests and PrefQuest, one participant did not fill out the 24 h recall, and one did not fill out the TasteFFQ questionnaire, resulting in 178 individuals included in the data analyses. Table 2 shows the characteristics of the participants.

Table 2
Demographic, anthropometric and socio-economic Characteristics of participants ($n = 178$).

	Mean ± s.d. / Frequency	Range / %
Sex		
-Females	123	69 %
-Males	55	31 %
Age (years)	35 ± 15	18–65
Weight (kg)	71 ± 12	46–106
BMI (kg/m^2)	23 ± 3	19–30
Weight status		
-Normal weight (BMI 18.5–24.9 kg/m^2)	130	73 %
-Overweight (BMI 25–30.0 kg/m^2)	48	27 %
Diet		
-No	149	84 %
-Yes	29	17 %
Employment status		
-Student	76	43 %
-Working	83	47 %
-No job, not looking for a job	5	3 %
-No job, looking for a job	5	3 %
-Retired	5	3 %
Education level		
-Lower/primary	5	3 %
-Intermediate	69	39 %
-Higher	104	58 %
Smoking		
-Yes	42	24 %
-No	136	76 %

The participants' mean age was 35 ± 15 years, mean BMI was 23 ± 3 kg/m^2 and the majority (69 %) were women.

3.2. Sweetness liking measures

3.2.1. Psychohedonic sweetness functions

Outcome measures indicated that the middle sweetness level (L-0) was the most liked and preferred. The liking scores (Sweet-Food-Liking) exhibited typical inverted U-shape psychohedonic functions (Fig. A1, Appendix), with significant differences noted between concentration levels ($F_{(4,5017)} = 129.1$, $p < .001$) and test foods ($F_{(5,5017)} = 113.0$, $p < .001$) (Table 3). The mean Sweet-Food-Preferred-Concentration score of 3.2 ± 0.7 reflected a general preference for moderate sweetness, with individual scores ranging from 1.6 to 4.8, indicating considerable variation in sweetness preferences among participants.

3.2.2. Sweet liker phenotype

Participants were evenly distributed among Sweet Dislikers ($n = 62$, 35 %), Moderate Sweet Likers ($n = 58$, 32.5 %) and Sweet Likers ($n = 58$, 32.5 %), according to the Sweet-Liker-Phenotype classification.

3.2.3. General liking for sweet foods and sweet fat foods

Mean PrefQuest-Sweet score for the whole population was 3.4 ± 0.8 (range:1.4–7.1), and PrefQuest-Fat-Sweet scores had a mean of 4.4 ± 1 (range:1.4–7.6).

3.3. Associations between sweetness liking measures

Sweet-Food-Liking scores differed between Sweet-Liker-Phenotype groups ($F_{(2,175)} = 27.9$, $p < .001$) and also the shape of psychohedonic function was different ($F_{(8,5150)} = 22.0$, $p < .001$). Averaged across all sweet test foods and concentration levels, Sweet Likers had the highest Sweet-Food-Liking scores (M = 50, 95 %CI [48, 52]), followed by Moderate Sweet Likers (M = 45, 95 %CI [43, 47]) and Sweet Dislikers (M = 38, 95 %CI [36, 40]). The three sweet liker phenotypes also differed in their liking scores across different concentration levels (Fig. 1, panel A). Differences in Sweet-Food-Liking ratings for mid-level sweetness (L-0) between Sweet Likers and Sweet Dislikes ($t_{(589)} = -4.4$, $p = .001$), and at high concentration levels (L+1 and L+2) between all three phenotype groups (all comparisons $p < .001$), were observed. At the lower sweetness concentration levels (L-2 and L-1) Sweet-Food-Liking ratings did not differ between the three groups.

Table 3
Mean (± s.d.) Sweet-Food-Liking for all test foods across five intensity concentration levels (L-2, L-1, L-0, L+1, L+2) (N = 178).

Method (domain, scale)	Test food	Liking score overall	Intensity concentrations levels				
			L-2	L-1	L-0	L+1	L+2
Ranking on a scale* (Sweet-Food-Liking, 0–100)	Strawberry flavoured lemonade	47 ± 25	48 ± 21^{a}	54 ± 21^{b}	55 ± 21^{b}	44 ± 26^{a}	32 ± 26^{c}
	Chocolate flavoured custard	47 ± 26	33 ± 25^{a}	46 ± 25^{b}	58 ± 22^{c}	54 ± 25^{c}	43 ± 26^{b}
	Plain Cake	51 ± 23	38 ± 22^{ad}	51 ± 21^{bd}	61 ± 20^{c}	57 ± 21^{bc}	49 ± 24^{d}
	Watermelon flavoured lemonade	38 ± 24	31 ± 23^{a}	37 ± 23^{b}	44 ± 23^{c}	44 ± 25^{c}	35 ± 24^{ab}
	Elderflower flavoured custard	31 ± 23	24 ± 18^{a}	36 ± $22b^{c}$	41 ± 23^{c}	34 ± 24^{b}	22 ± 23^{a}
	Tamarind flavoured cake	49 ± 22	36 ± 20^{a}	52 ± 20^{b}	59 ± 18^{c}	52 ± 24^{b}	46 ± 24^{b}
		$p < .001$‡					

* Sweet-Food-Liking (Sweet Food Liking, 0–100) data analysed using Linear Mixed Models.

‡ p-value present differences between test foods overall

[a, b, c, d, e] for each row, different letters indicate statistically significant differences at $p < .05$ (For rating (liking) Bonferroni post hoc correction applied.

Additionally, the Sweet-Liker-Phenotype groups differed significantly in their Sweet-Food-Preferred-Concentration (($F_{(2,175)} = 22.6$, $p < .001$); all comparisons $p < .01$, see Fig. 1, panel B). Sweet Likers had the highest mean Sweet-Food-Preferred-Concentration (M = 3.6, 95 %CI [3.4, 3.8]), followed by Moderate Sweet Likers (M = 3.2, 95%-CI [3.0, 3.3]), and Sweet Dislikers (M = 2.8, 95%-CI [2.7, 3.0]).

Sweet-Liker-Phenotype groups also differed in liking responses for PrefQuest-Sweet ($\chi^2_{(2)} = 16.2$, $p < .001$) and PrefQuest-Fat-Sweet ($\chi^2_{(2)} = 24.8$, $p < .001$). Sweet Likers had a higher mean PrefQuest-Sweet (M = 3.7, 95%-CI [3.5, 3.9]) and PrefQuest-Fat-Sweet (M = 4.9, 95%-CI [4.6, 5.1]) scores, compared to Sweet Dislikers (PrefQuest-Sweet: M = 3.1, 95%-CI [2.9, 3.3]; PrefQuest-Fat-Sweet: M = 3.9, 95%-CI [3.8, 4.2]), but not compared to Moderate Sweet Likers (PrefQuest-Sweet: M = 3.4, 95 %CI [3.2, 3.5]; PrefQuest-Fat-Sweet: M = 4.4, 95%-CI [4.1, 4.7]), as shown in Fig. 2, (PrefQuest-Sweet: ($\chi^2_{(2)} = 16.2$, $p < .001$); PrefQuest-Fat-Sweet: ($\chi^2_{(2)} = 24.8$, $p < .001$)).

There was no difference between Sweet-Food-Liking groups in PrefQuest-Sweet scores ($\chi^2_{(2)} = 3.8$, $p = .148$). However, PrefQuest-Fat-Sweet scores differed significantly across Sweet-Food-Liking groups ($\chi^2_{(2)} = 17.6$, $p < .001$). Post-hoc analysis showed that the low Sweet-Food-Liking group (M = 3.9, 95%-CI [3.7, 4.2]) scored significantly lower than the high group (M = 4.7, 95%-CI [4.5, 4.9]), while the medium group (M = 4.5, 95%-CI [4.2, 4.7]) did not significantly differ from either. There was also a significant difference between Sweet-Food-Preferred-Concentration groups in PrefQuest-Sweet ($\chi^2_{(2)} = 13$, $p = .001$) and PrefQuest-Fat-Sweet ($\chi^2_{(2)} = 11$, $p = .004$) scores. For both PrefQuest oucomes, post-hoc pairwise comparisons showed that the low Sweet-Food-Preferred-Concentration (PrefQuest-Sweet: M = 3.1, 95%-CI [2.9, 3.5]; PrefQuest-Fat-Sweet: M = 4.0, 95%-CI [3.9, 4.3]) had lower scores than both the medium (PrefQuest-Sweet: M = 3.4, 95%-CI [3.2, 3.6]; PrefQuest-Fat-Sweet: M = 4.5, 95%-CI [4.2, 4.8]) and the high group (PrefQuest-Sweet: M = 3.6, 95%-CI [3.4, 3.8]; PrefQuest-Fat-Sweet: M = 4.6, 95%-CI [4.3, 4.9]). However, there was no significant difference between the medium and high groups. Differences in PrefQuest-Sweet and PrefQuest-Fat-Sweet scores between Sweet-Food-Liking and Sweet-Food-Preferred-Concentration groups are shown in Fig. 3.

3.4. Intake of sweet foods and sugar

Participants reported on average 1890 ± 642 kcal/day (7,9 ± 2,7 MJ/day), with protein, fat, and carbohydrates, contributing respectively 16 %, 35 % and 46 % of total energy intake (Table 4). Reported sugar intake was on average 83 ± 34 g. The average daily intake of sweet foods was 389 ± 274 g, making up 24 % of the total energy intake and 14 % of total weight. The TasteFFQ showed that long-term sweet food intake accounted for 22 % of total consumed weight.

3.5. Association between sweetness liking measures, sweet food and sugar intake

Table 5 gives a summary of the association between the sweet liking measures and the intakes of mono- and di-saccharides and sweet food. None of the sweetness liking measures, except PrefQuest-Sweet, was associated with sugar intake, the amount of sweet food consumed, or its contribution to total energy from sweet foods consumed (Fig. 4 and Table 5). There was no difference between Sweet-Food-Liking groups in terms of mono- and di-saccharides intake ($\chi^2_{(2)} = 2.5$, $p = .28$), energy intake from sweet foods ($\chi^2_{(2)} = 0.7$, $p = .70$) and weight from sweet

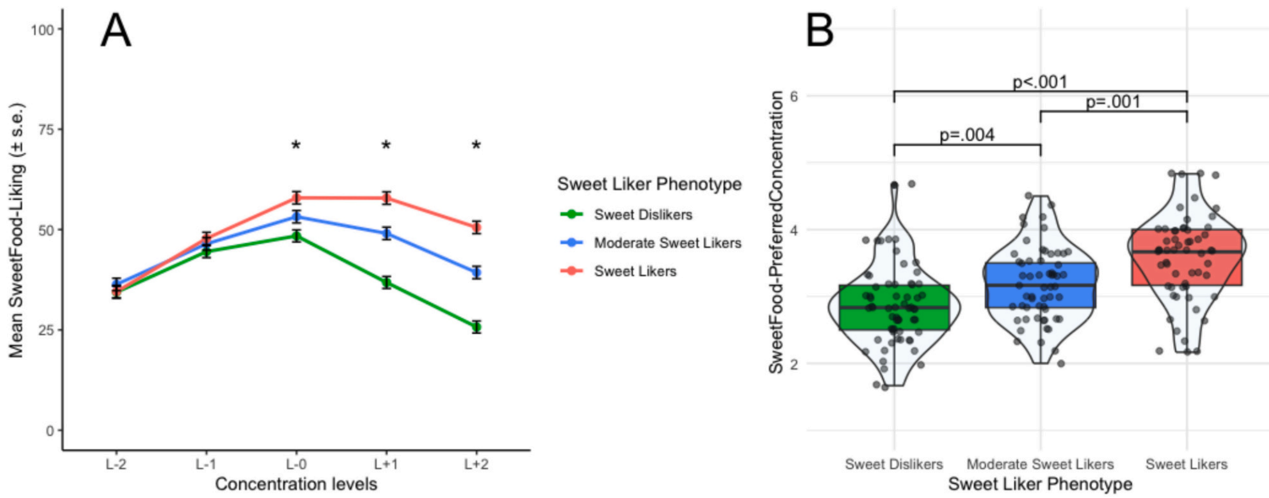

Fig. 1. Differences in Sweet-Food-Liking and Sweet-Food-Preferred-Concentration between Sweet-Liker-Phenotypes (Sweet Dislikers (n = 62), Moderate Sweet Likers (n = 58), and Sweet Likers (n = 58)). **A:** Mean Sweet-Food-Liking (± s.e.) for varying sweetness levels (L-2, L-1, L-0, L+1, L+2) across Sweet Liker Phenotypes '*' indicates a significant difference between liking scores between phenotypes at a specific concentration level. Data were analysed by using mixed models: Sweet-Food-Liking ~ Sweet-Liker-Phenotype group × concentration level. **B:** Box plots showing Sweet-Food-Preferred-Concentration scores, with individual data points across Sweet-Liker-Phenotypes.

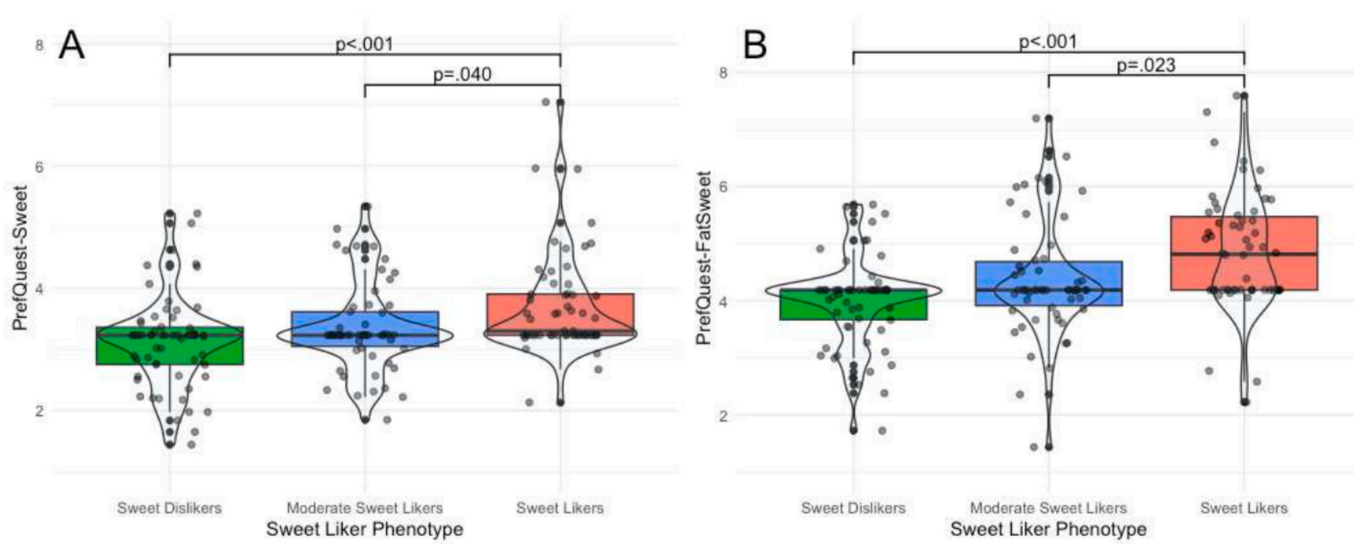

Fig. 2. Difference in PrefQuest Scores between Sweet-Liker-Phenotype groups (Sweet Dislikers (n = 62), Moderate Sweet Likers (n = 58), and Sweet Likers (n = 58)). A: Box plots showing differences in PrefQuest-Sweet between Sweet Liker Phenotypes. **B**: Box plots showing differences in PrefQuest-Fat-Sweet between Sweet-Liker-Phenotypes.

foods (24 h recall: $\chi^2_{(2)} = 0.1$, $p = .95$; TasteFFQ: $\chi^2_{(2)} = 0.7$, $p = .69$). Similarly, there were no significant differences between the Sweet-Food-Preferred-Concentration groups for mono- and di-saccharides intake ($\chi^2_{(2)} = 1.7, p = .43$), energy intake from sweet foods ($\chi^2_{(2)} = 0.5, p = .78$) and weight of sweet foods (24 h recall: $\chi^2_{(2)} = 0.2, p = .92$; TasteFFQ: $\chi^2_{(2)} = 1.8, p = .41$). Sweet-Liker-Phenotypes, that is Sweet Dislikers ($n = 62$), Moderate Sweet Likers ($n = 58$), and Sweet Likers (n = 58) also did not differ in mono- and di-saccharides intake ($\chi^2(2) = 2.1$, $p = .36$), energy intake from sweet foods ($\chi^2_{(2)} = 1.7$, p = .43) and weight from sweet foods (24 h recall: $\chi^2_{(2)} = 0.1$, $p = .96$; TasteFFQ: $\chi^2_{(2)} = 1.8$, $p = .39$). Lastly, there were no significant differences between the PrefQuest-Fat-Sweet groups for mono- and di-saccharides intake ($\chi^2_{(1)} = 0.1, p = .76$), energy intake from sweet foods ($\chi^2_{(1)} = 0.3, p = .61$), and weight of sweet foods (24 h recall: $\chi^2_{(1)} = 1.1, p = .29$; TasteFFQ: $\chi^2_{(1)} = 1.6, p = .19$).

An association between PrefQuest-Sweet and intake of simple sugars, energy from sweet foods, and the weight of sweet food consumed from the 24 h recall was observed. Intake of mono- and di-saccharides was higher in the PrefQuest high sweet likers (M = 90 g, 95%-CI [83, 98]) vs. the PrefQuest low sweet likers (M = 77 g, 95%-CI [77, 84]) ($\chi^2_{(1)} = 6.10$, $p = .014$). Additionally, PrefQuest high sweet likers (M_{energy} = 27 %, 95%-CI [24, 29]; $M_{intake(w\%)}$ = 16 %, 95%-CI [13, 18]) had a higher energy and higher intake of sweet foods compared to the PrefQuest low sweet likers (M_{energy} = 23 %, 95 %CI [20, 25]; $M_{intake(w\%)}$ = 13 %, 95%-CI [11, 15]) (energy sweet foods: $\chi^2_{(1)} = 5.82$, $p = .016$; weight sweet foods: $\chi^2_{(1)} = 5.05$, $p = .025$) (Fig. 2). The two groups did not differ in sweet food intake assessed with the TasteFFQ ($\chi^2_{(1)} = 3.38$, $p = .066$).

4. Discussion

The aim of the current analysis was to assess the concurrence of different sweetness liking measures and investigate if they relate to sweet food and sugar intake. The results of this study show that distinct

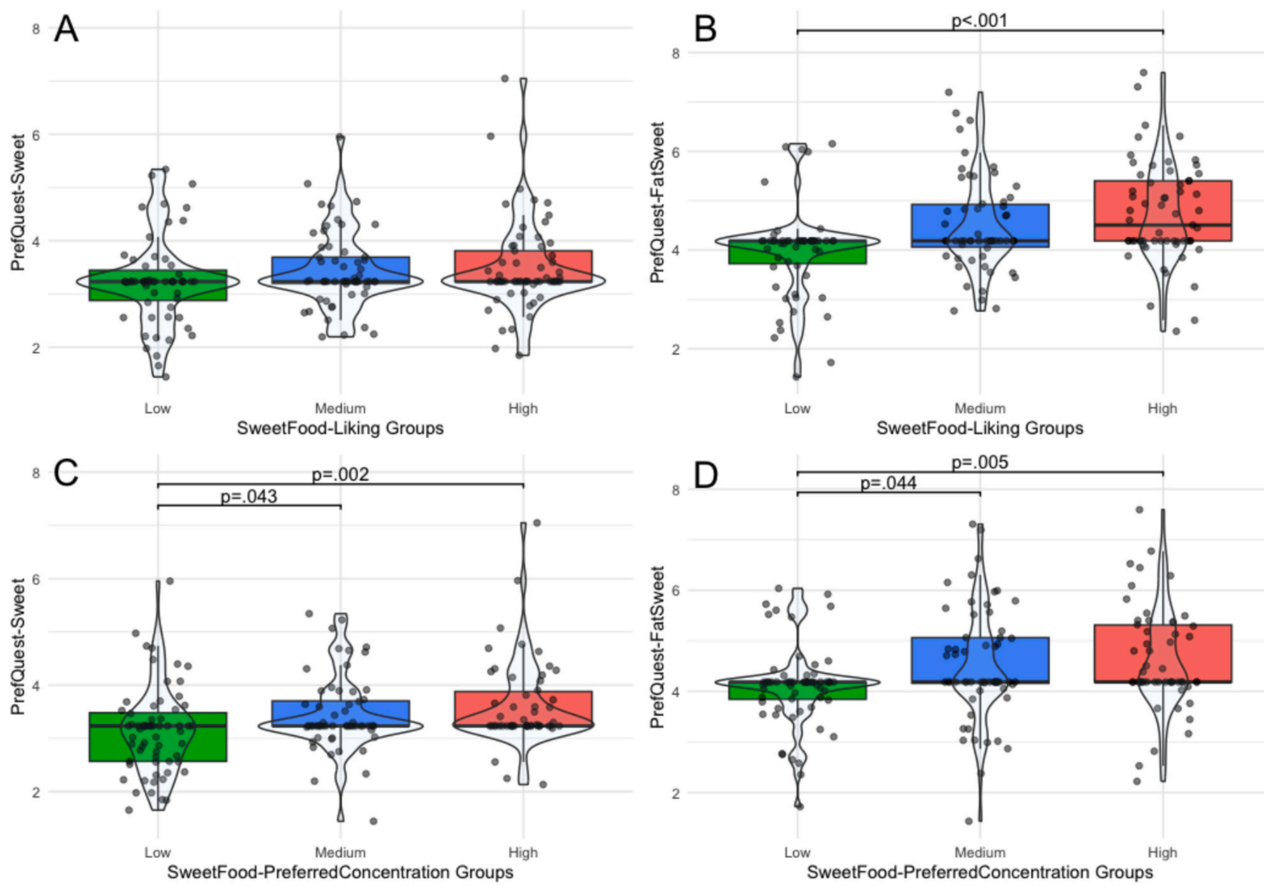

Fig. 3. Difference in Sweet-Food-Liking and Sweet-Food-Preferred-Concentration groups and PrefQuest Scores. A and **B** display the difference between Sweet-Food-Liking groups (Low (n = 59, M), Medium (n = 58), and High (n = 61) in their PrefQuest-Sweet and PrefQuest-Fat-Sweet scores. **C** and **D** show the difference between the Sweet-Food-Preferred-Concentration groups (Low (n = 64), Medium (n = 60), and High (n = 54) in their PrefQuest-Sweet and PrefQuest-Fat-Sweet scores.

Table 4
Energy, nutrient and sweet food intake of participants (N = 178).

		Mean ± s.d.	Range
24-h recall	Energy Intake (kJ)	7,9 ± 2,7	3,5-15,9
	Energy Intake (kcal)	1890 ± 642	836–3801
	Protein Intake (en%)	16 ± 5	7–38
	Fat (en%)	35 ± 10	14–64
	Carbohydrate (en%)	46 ± 9	13–68
	Mono- and di-saccharides (g)	83 ± 34	17–179
	Intake from sweet foods (kcal)	457 ± 295	0–1746
	Intake from sweet foods (en%)	24 ± 12	0–64
	Amount of sweet foods (g)	389 ± 274	0–1570
	Amount of sweet foods (w%)	14 ± 11	0–70
Taste FFQ	Amount of sweet foods (w%)	22 ± 13	3–73

methods to measure sweetness liking are in agreement with each other. We found weak and inconsistent associations between sweetness liking measures, sugar and sweet food intake.

This study differs from previous research by incorporating three distinct measures that capture various dimensions of sweetness liking: ranging from specific taste ratings to broader behavioural preferences. The Sweet-Food-Liking and Sweet-Food-Preferred-Concentration measures evaluate sweetness liking across a range of sweetness intensities in six familiar and unfamiliar foods, providing insights into how liking changes with increasing sweetness intensity. This concept of measuring sweetness liking is in line with suggestions from Mela and Risso (2024) to use different foods and different textures in order to create some representativeness of a general consumption pattern. In contrast, the Sweet-Liking-Phenotype method captures liking based on a single, highly concentrated sweetness stimulus (1 M sucrose), focusing more on an intense sweet experience rather than a range. The PrefQuest-Sweet

Table 5
Associations between hedonic measures for sweet foods, sweet food and sugar intake. A "✔" indicates statistically significant association, while a "×" denotes no association between sweetness liking measure and intake.

		24 h recall			Taste FFQ
		Intake of mono- and di-saccharides (g)	Energy Intake from sweet foods (en%)	Amount of sweet foods (w%)	Amount of sweet foods (w%)
Liking & preference for sweet foods	Sweet-Food-Liking	×	×	×	×
	Sweet-Food-Preferred-Concentration	×	×	×	×
Sweet Liker Phenotype		×	×	×	×
General Liking (PrefQuest)	PrefQuest-Sweet	✔	✔	✔	×
	PrefQuest-Fat-Sweet	×	×	×	×

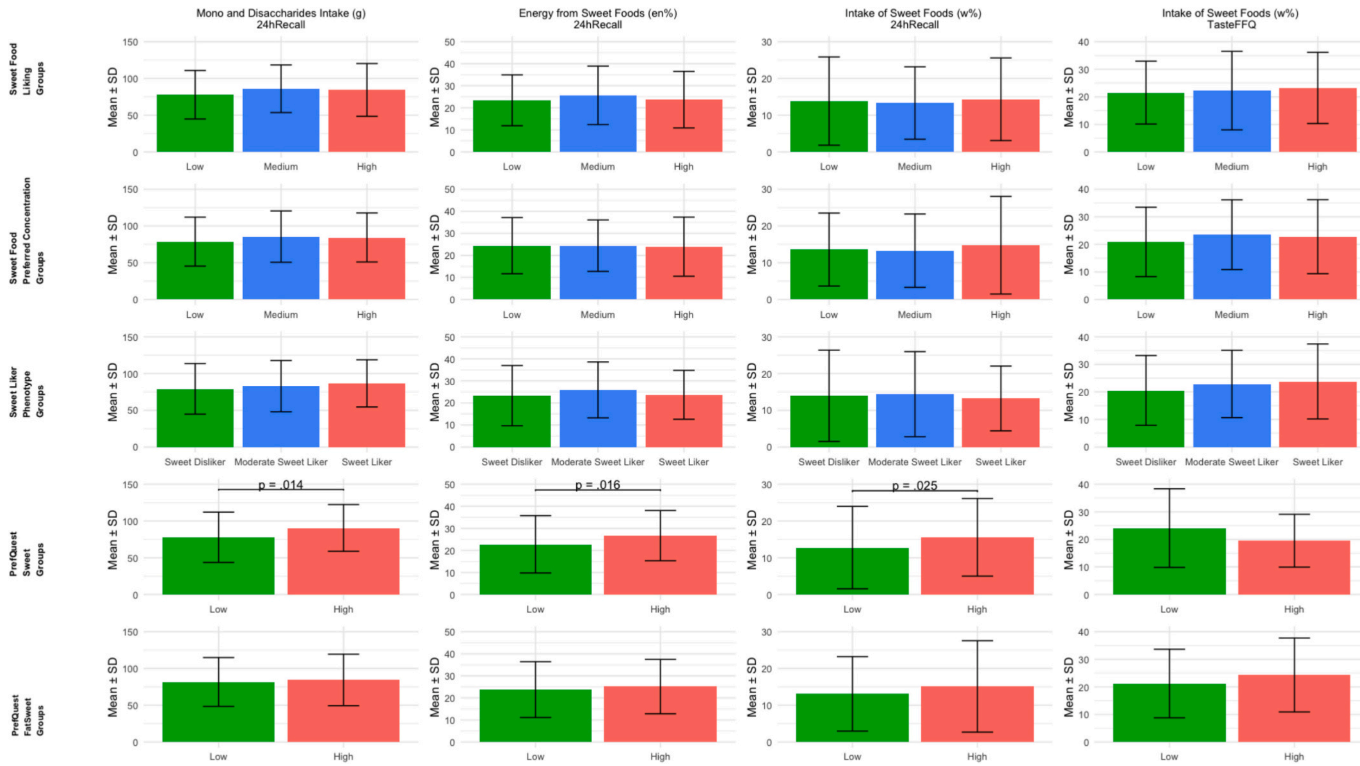

Fig. 4. Overall mean ± s.d. intakes of sugar (mono- and di-saccharide), % energy coming from sweet foods, weight intake of sweet foods (based on 24 h recall and TasteFFQ) across different hedonic measures. Sweet Food Liking (Sweet-Food-Liking) groups - low (n = 59), medium (n = 58), and high (n = 61) - did not differ in their intake of simple sugars, energy, or the amount of sweet food consumed. Sweet Food Average Preferred concentration (Sweet-Food-Preferred-Concentration) groups -low (n = 64), medium (n = 64), and high (n = 54) - did not differ in their intake of simple sugars, energy, or the amount of sweet food consumed. Sweet Liker Phenotype (Sweet-Liker-Phenotype) groups - Sweet Dislikers (n = 62), Moderate Sweet Likers (n = 58), and Sweet Likers (n = 58) - did not differ in their intake of simple sugars, energy, or the amount of sweet food consumed. PrefQuest-Sweetweet groups - low (n = 110) and high (n = 68) - did differ in their intake of simple sugars, energy, or the amount of sweet food consumed, assessed with 24 h recall, the high group consuming significantly more sugar and sweet foods. No difference in sweet foods consumed assessed with TasteFFQ. PrefQuest-Fat-Sweet groups -low (n = 114) and high (n = 64) - did not differ in their intake of simple sugars, energy, or the amount of sweet food consumed.

and PrefQuest-Fat-Sweet measures assess liking based on self-reported liking responses and behavioural actions to sweet foods, sugar, and sweeteners, rather than through direct tasting. Despite being conceptually different, we observed that the different measures of sweetness liking were congruent with each other.

Differences in Sweet-Food-Liking and Sweet-Food-Preferred-Concentration scores between all Sweet-Liking-Phenotype groups were observed. Sweet Likers preferred higher sweetness levels and had overall higher liking for sweet foods compared to the other phenotype groups. However, a closer examination of psychohedonic functions revealed that discrepancies in liking were mostly due to differences between mid and high sweetness concentrations, rather than differences at lower concentrations. Given that the Sweet-Liking-Phenotype method is based on evaluating a highly sweet 1.0 M sucrose solution, it is not surprising that liking scores differ more at higher sweetness levels. Interestingly, Armitage et al. (2024) reported significant differences between the three phenotypes using a weaker sucrose solution (0.58 M). The latter closely resembles the intensity of everyday sweet products and may be comparable to the L-0 sweetness level in our study. Consistent with Armitage et al. (2024), our results indicate differences in Sweet-Food-Liking scores at the mid-level, though only between Sweet Likers and Sweet Dislikers. Our findings show that the Sweet-Liking-Phenotype method distinguishes between individuals with extreme levels of liking (sweet likers vs. sweet dislikes) for actual sweet foods with mid to high sweetness intensities yet raises questions about how the method represents the liking of foods with lower sweetness intensities. This is likely because the 1 M sucrose solution used for classification is a very sweet stimulus, making it more reflective of a specific preference for products with mid to high sweetness levels. Since not all foods have highly sweet intensity, future research should assess preferences across a wider range (low to high) of sweetness to better reflect sweetness levels of diverse foods.

Our results also suggest a strong relationship between the PrefQuest-Sweet and PrefQuest-Fat-Sweet measures and both Sweet-Food-Preferred-Concentration and Sweet-Liking-Phenotype. Sweet-Food-Preferred-Concentration was associated with PrefQuest-Sweet and PrefQuest-Fat-Sweet, indicating that individuals with higher self-reported liking via PrefQuest also had a preference for higher sweetness levels in sweet-tasting foods. On the other hand, the Sweet-Food-Liking measure was only associated with PrefQuest-Fat-Sweet and not with PrefQuest-Sweet measure. This may be explained by the composition of the stimuli for the sweet-food -liking measure, as four out of six test foods in our study contained fat. These foods represent those commonly available in the Dutch food supply, where sweet is commonly consumed in combination with fat, and subtle differences between sweet foods and fat-sweet foods in taste tests have previously been reported (Drewnowski et al., 1985). Moreover, the Sweet-Liking-Phenotype groups differed in PrefQuest-Sweet and PrefQuest-Fat-Sweet scores: Sweet Likers had higher scores compared to Sweet Dislikers, while Moderate Sweet Likers did not significantly differ from either group. These findings are consistent with previous studies by Armitage et al. (2023) and Kim et al. (2014), which showed that Sweet Likers have a preference for sweet, sweet and fat (Armitage et al., 2023), and sweet and savoury foods (Kim et al., 2014). Taken together, our results reinforce the notion that one can reliably measure the concept of sweetness liking, using different measures.

We found no consistent associations between sweet taste liking and intake of sweet foods or sugars. As shown in Table 5, only general self-reported liking for sweet foods (PrefQuest-Sweet) was linked to increased intake of mono- and di-saccharides, as well as higher intake from sweet foods (%energy and % weight), assessed with 24-h recall. However, no association was found between PrefQuest-Sweet and intake of sweet foods measured by the TasteFFQ. This discrepancy may stem from differences in dietary assessment methods: the single 24-h recall reflects short-term intake, while the TasteFFQ estimates habitual intake over the last month. FFQs rely more on participants' memory and are generally less accurate, particularly for foods consumed infrequently or on specific occasions (Brouwer-Brolsma et al., 2020). Future research may use multiple 24-h recalls to improve intake reliability and better understand the link between sweet taste liking and habitual consumption.

For other sweetness liking measures in our study, we found no effects of sweet taste liking on sweet food and sugar intake. Our findings align with the study by Papantoni et al. (2021), which reported no association between liking for a sweet tasting food and daily sugar intake. They also align with findings from Armitage et al. (2023), who also measured liking and sugar intake concurrently across sweet liker phenotypes. While these authors observed clear differences in liking for sweet and sweet-fat foods between phenotypes, they found no significant differences in sugar intake (Armitage et al., 2023). Similar findings have been reported in other studies examining sugar and carbohydrate intake across sweet liker phenotypes (Iatridi et al., 2020; Methven et al., 2016). The observed positive relationship between PrefQuest-Sweet and sweet food intake in our study, may be attributed to the fact that the PrefQuest measure includes behavioural questions such as whether respondents add sweeteners to particular foods. Such questions may be more associated with sugar-related behaviour than to liking/preferences per se. This may also explain why Lampure et al. (2020) did find positive associations between their PrefQuest-Sweet measures and sugar/sweet food intake, whereas other more strictly sensory based studies do not show this association. While liking for sweet foods is often assumed to be a central driver of intake, our findings, along with previous research, suggest that this relationship is not always straightforward. Hayes (2023) describes this phenomenon as a so-called causal chain, where formulation influences sensation, sensation influences liking and liking influences intake. However, each step introduces variability due to measurement error and external influences, weakening the direct association between liking and intake. For instance, while our results show differences in liking between Sweet-Liker-Phenotypes, these differences were not consistently reflected in sweet food intake measures.

Inconsistent results between liking and intake in this study and others may be due to differences in methods for assessing sweet taste liking (e.g., psychophysical measurements, type of sweet stimuli, questionnaires) and dietary intake (e.g., food records, 24-h recalls, food frequency questionnaires) (Tan & Tucker, 2019). This study employed a robust approach to assess sweet taste liking. PrefQuest, one of the methods used, relies solely on self-reports and does not involve direct tasting. In contrast, the other two measures provide a sensory experience by requiring participants to taste stimuli. The psychohedonic method, which includes tasting foods across multiple sweetness levels, offers detailed data but is time-consuming. The Sweet-Liking-Phenotype method, while simpler and involving only a sugar solution, may not capture the full sensory experience across a variety of different sweetness levels. Our findings suggest that the Sweet-Liking-Phenotype is effective at distinguishing individuals with extreme sweetness preferences (Sweet Likers vs. Sweet Dislikers) but may lack the sensitivity to distinguish between individuals with moderate preferences. For capturing these subtle differences, more sensitive methods, such as psychohedonic testing, may be necessary.

In this study, sweet food intake was measured using data from the Taste Database (Mars et al., 2020) which offers a precise assessment of oro-sensory perceptual experiences of sweet taste. This approach goes beyond traditional methods that rely solely on self-reported intake of added sugars or sweet foods (Mela & Risso, 2024). By using a Taste Database, this enabled us to consider the diverse sweetness profiles of foods and beverages consumed, which can vary widely in their sweetness despite containing sugars and/or sweeteners. Additionally, our study employed two methods to assess sweet food intakes, a 24-h dietary recall and the TasteFFQ. The intake of sweet foods, expressed as a percentage of weight, differed between the two methods: the TasteFFQ indicated that, on average, study participants consumed 22 % of foods that are sweet-tasting, while the 24-h recall showed a lower proportion at 14 %. The TasteFFQ used in our study has not yet been validated, which could lead to inaccuracies in dietary assessment. Future validation of the TasteFFQ is essential to ensure accurate reflection of dietary intake. Furthermore, the 24-h recall data was based on only one day and the data indicated that, on average, study participants consumed 1897 kcal, which falls below both the recommended energy intake for a moderately active woman (2000 kcal) (European Food Safety Authority, 2009), and the average energy intake observed in the Netherlands (2010 kcal) (RIVM, 2021). Moreover, the mean total sugar intake of 83 g was lower than the average of 93 g for the total population of the Netherlands (RIVM, 2021). These findings may suggest underreporting, a well-known issue in dietary assessment (Ravelli & Schoeller, 2020). Additionally, our results are not fully generalizable, as the sample is not representative of the Dutch population in terms of sex, age, and BMI, with fewer participants with overweight and obesity (Statista, 2023). Although our approach builds upon previous attempts by employing precise measurements of exposure to sweet taste, self-reported measures of dietary intake rely on memory, may be biased by misreporting, and should be interpreted with caution (Ravelli & Schoeller, 2020). Future studies should combine dietary assessment data with biomarker data for a more accurate evaluation of sweet-tasting compound intake (Buso et al., 2024; Diepeveen-de Bruin et al., 2023; Tasevska, 2015) and its relationship with individual liking for sweet taste. Biomarkers, such as urinary excretion of sugars and some sweeteners, offer a more objective measure of intake (Diepeveen-de Bruin et al., 2023), however, these tell us nothing about individual perceptions of a taste. Thus, combining both (biomarkers and self-reported intake), alongside perceptions of taste intensity could improve dietary assessment accuracy and our understanding of sweet taste liking and intake.

5. Conclusion

This study examined the relationship between hedonic measures and intake from the perspective that liking for sweetness influences consumption of sugar and sweet foods. This approach assumes that individuals who have a stronger preference/liking for sweet foods are more likely to consume them more often and in larger amounts. Our results revealed that sweetness preferences vary across individuals and can be consistently measured using different approaches. Moreover, our results show that high sweetness liking, as measured through sensory tests, showed no relationships with actual sugar and sweet food intake. In contrast, self-reported measures of sweet taste preference (via PrefQuest questionnaire) demonstrated significant relationships with sugar and sweet food intake assessed with a 24 h recall. These findings cast doubt on assumptions that sweet taste liking alone drives high sugar and sweet food intake. Future research should explore the reverse relationship - whether the intake of sweet foods influences liking. This concept suggests that the frequency and amount of sweet food consumption could shape or modify an individual's preference for sweet foods over time. Investigating the exposure-liking relationship could provide insights into how dietary habits impact food preferences, potentially offering new strategies for dietary interventions aimed at reducing sweet food consumption.

CRediT authorship contribution statement

Eva M. Čad: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Merel van der Kruijssen:** Writing – review & editing, Formal analysis, Data curation. **Claudia S. Tang:** Writing – review & editing, Methodology, Investigation, Data curation. **Leoné Pretorius:** Writing – review & editing, Investigation, Data curation. **Hanne B.T. de Jong:** Writing – review & editing, Methodology, Data curation. **Monica Mars:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Katherine M. Appleton:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Kees de Graaf:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Ethical statement

Ethical approval for the involvement of human subjects in this study was granted by METC-WU, ABR no. NL72134, 10/05/20.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: EMČ, LP, HdeJ and MvdK and MM did not have any personal financial interests or professional relationships related to the subject matter to disclose withing the last 3 yrs. CST is currently employed by Heinz-Kraft; her involvement in the study started before this employment; her co-authorship is based on her previous affiliation. KdG is a member of the Global Independent Nutrition Advisory Board of the Mars company. KMA has received research funding from Unilever R&D, ILSI-North America, the International Sweeteners Association, The Coca Cola Company and Ajinomoto Health & Nutrition North America Inc. KMA has received speaker's expenses from the International Sweeteners Association; PepsiCo; ILSI-North America and EatWell Global.

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Appendix A. Psychohedonic functions for the sweet test foods

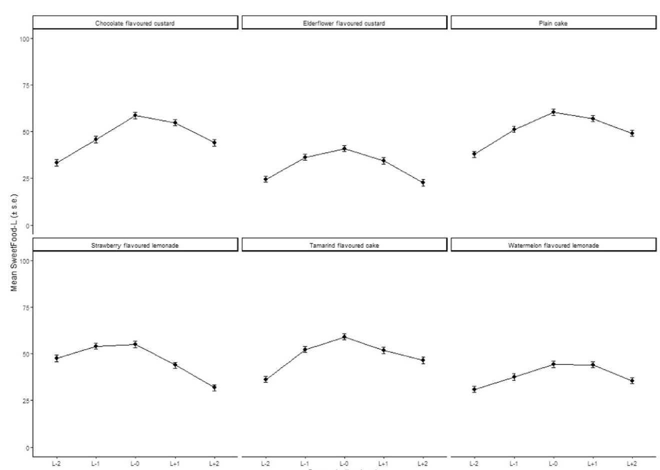

Fig. A1. Mean (s.e.) SF-Liking scores as psychohedonic functions for the six sweet test foods across different intensity levels (low-high; L-2, L-1, L-0, L+1, L+2).

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2025.105536.

Data availability

Data will be made available on request.

References

Appleton, K. M., Tuorila, H., Bertenshaw, E. J., de Graaf, C., & Mela, D. J. (2018). Sweet taste exposure and the subsequent acceptance and preference for sweet taste in the diet: Systematic review of the published literature. *The American Journal of Clinical Nutrition, 107*(3), 405–419. https://doi.org/10.1093/ajcn/nqx031

Armitage, R. M., Harvey, T., Green, P., Marzola, G., Iatridi, V., & Yeomans, M. R. (2024). Sweet-liking and the basic tastes. *Appetite, 199*. https://doi.org/10.1016/j.appet.2024.107434

Armitage, R. M., Iatridi, V., Thanh Vi, C., & Yeomans, M. R. (2023). Phenotypic differences in taste hedonics: The effects of sweet liking. *Food Quality and Preference, 107*. https://doi.org/10.1016/j.foodqual.2023.104845

Armitage, R. M., Iatridi, V., & Yeomans, M. R. (2021). Understanding sweet-liking phenotypes and their implications for obesity: Narrative review and future directions. *Physiology & Behavior, 235*, Article 113398. https://doi.org/10.1016/j.physbeh.2021.113398

Brouwer-Brolsma, E. M., Lucassen, D., de Rijk, M. G., Slotegraaf, A., Perenboom, C., Borgonjen, K., … de Vries, J. H. M. (2020). Dietary intake assessment: From traditional paper-pencil questionnaires to technology-based tools. In I. N. Athanasiadis, S. P. Frysinger, G. Schimak, & W. J. Knibbe (Eds.), *Environmental software systems. Data science in action* (pp. 7–23). Springer International Publishing. https://doi.org/10.1007/978-3-030-39815-6_2.

Buso, M. E., Boshuizen, H. C., Naomi, N. D., Maho, W., Diepeveen-de Bruin, M., Balvers, M. G., … Brouwer-Brolsma, E. M. (2024). Relative validity of habitual sugar and low/no-calorie sweetener consumption assessed by food frequency questionnaire, multiple 24-h dietary recalls and urinary biomarkers: An observational study within the SWEET project. *The American Journal of Clinical Nutrition, 119*(2), 546–559. https://doi.org/10.1016/j.ajcnut.2023.11.019

Čad, E. M., Tang, C. S., de Jong, H. B. T., Mars, M., Appleton, K. M., & de Graaf, K. (2023). Study protocol of the sweet tooth study, randomized controlled trial with partial food provision on the effect of low, regular and high dietary sweetness exposure on sweetness preferences in Dutch adults. *BMC Public Health, 23*(1), 77. https://doi.org/10.1186/s12889-022-14946-4

Čad, E. M., Tang, C. S., Mars, M., Appleton, K. M., & de Graaf, K. (2023). How sweet is too sweet? Measuring sweet taste preferences and liking in familiar and unfamiliar foods amongst Dutch consumers. *Food Quality and Preference, 111*. https://doi.org/10.1016/j.foodqual.2023.104989

Deglaire, A., Méjean, C., Castetbon, K., Kesse-Guyot, E., Urbano, C., Hercberg, S., & Schlich, P. (2012). Development of a questionnaire to assay recalled liking for salt, sweet and fat. *Food Quality and Preference, 23*(2), 110–124. https://doi.org/10.1016/j.foodqual.2011.08.006

Diepeveen-de Bruin, M., Maho, W., Buso, M. E. C., Naomi, N. D., Brouwer-Brolsma, E. M., Feskens, E. J. M., & Balvers, M. G. J. (2023). Development and validation of a UPLC-MS/MS method for the quantification of sugars and non-nutritive sweeteners in human urine. *Journal of Chromatography. B, Analytical Technologies in the Biomedical and Life Sciences, 1225*, Article 123741. https://doi.org/10.1016/j.jchromb.2023.123741

Drewnowski, A., Brunzell, J. D., Sande, K., Iverius, P. H., & Greenwood, M. R. C. (1985). Sweet tooth reconsidered: Taste responsiveness in human obesity. *Physiology & Behavior, 35*(4), 617–622. https://doi.org/10.1016/0031-9384(85)90150-7

European Food Safety Authority. (2009). Review of labelling reference intake values - scientific opinion of the panel on dietetic products, nutrition and allergies on a request from the commission related to the review of labelling reference intake values for selected nutritional elements. *EFSA Journal, 7*(5). https://doi.org/10.2903/j.efsa.2009.1008

Finlayson, G., King, N., & Blundell, J. E. (2007). Is it possible to dissociate "liking" and "wanting" for foods in humans?. A novel experimental procedure. *Physiol Behav., 90* (1), 36–42. https://doi.org/10.1016/j.physbeh.2006.08.020. Epub 2006 Oct 17. PMID: 17052736.

Garneau, N. L., Nuessle, T. M., Mendelsberg, B. J., Shepard, S., & Tucker, R. M. (2018). Sweet liker status in children and adults: Consequences for beverage intake in adults. *Food Quality and Preference, 65*, 175–180. https://doi.org/10.1016/j.foodqual.2017.10.005

de Graaf, C., Kramer, F. M., Meiselman, H. L., Lesher, L. L., Baker-Fulco, C., Hirsch, E. S., & Warber, J. (2005). Food acceptability in field studies with US army men and women: Relationship with food intake and food choice after repeated exposures. *Appetite, 44*(1), 23–31. https://doi.org/10.1016/j.appet.2004.08.008

Hayes, J. E. (2023). Measuring sensory perception in relation to consumer behavior. In *Rapid sensory profiling techniques* (pp. 81–102). Woodhead Publishing.

Iatridi, V., Armitage, R. M., Yeomans, M. R., & Hayes, J. E. (2020). Effects of sweet-liking on body composition depend on age and lifestyle: A challenge to the simple sweet-liking-obesity hypothesis. *Nutrients, 12*(9). https://doi.org/10.3390/nu12092702

Iatridi, V., Hayes, J. E., & Yeomans, M. R. (2019a). Reconsidering the classification of sweet taste liker phenotypes: A methodological review. *Food Quality and Preference, 72*, 56–76. https://doi.org/10.1016/j.foodqual.2018.09.001

Iatridi, V., Hayes, J. E., & Yeomans, M. R. (2019b). Quantifying sweet taste liker phenotypes: Time for some consistency in the classification criteria. *Nutrients, 11*(1). https://doi.org/10.3390/nu11010129

Kim, J.-Y., Prescott, J., & Kim, K.-O. (2014). Patterns of sweet liking in sucrose solutions and beverages. *Food Quality and Preference, 36*, 96–103. https://doi.org/10.1016/j.foodqual.2014.03.009

Lampure, A., Adriouch, S., Castetbon, K., Deglaire, A., Schlich, P., Peneau, S., Fezeu, L., Hercberg, S., & Mejean, C. (2020). Relationship between sensory liking for fat, sweet or salt and cardiometabolic diseases: Mediating effects of diet and weight status. *European Journal of Nutrition, 59*(1), 249–261. https://doi.org/10.1007/s00394-019-01904-x

Lampure, A., Castetbon, K., Deglaire, A., Schlich, P., Peneau, S., Hercberg, S., & Mejean, C. (2016). Associations between liking for fat, sweet or salt and obesity risk in French adults: A prospective cohort study. *International Journal of Behavioral Nutrition and Physical Activity, 13*, 74. https://doi.org/10.1186/s12966-016-0406-6

van Langeveld, A., Teo, P. S., de Vries, J. H. M., Feskens, E. J. M., de Graaf, C., & Mars, M. (2018). Dietary taste patterns by sex and weight status in the Netherlands. *British Journal of Nutrition, 119*(10), 1195–1206. https://doi.org/10.1017/s0007114518000715

Mars, M., de Graaf, C., Teo, P. S., & van Langeveld, A. W. B. (2020). *Taste, Fat and Texture Database - taste values Dutch Foods Wageningen University & Research*. Doi: 10.17026_dans-xst-ughm.xml.

Martyn, D., Darch, M., Roberts, A., Lee, H. Y., Yaqiong Tian, T., Kaburagi, N., & Belmar, P. (2018). Low-/no-calorie sweeteners: A review of global intakes. *Nutrients, 10*(3). https://doi.org/10.3390/nu10030357

Mattes, R. D. (2024). Sensory nutrition: Lessons learned and opportunities. *Obesity (Silver Spring), 32*(8), 1421–1424. https://doi.org/10.1002/oby.24089

Meijboom, S., van Houts-Streppel, M. T., Perenboom, C., Siebelink, E., van de Wiel, A. M., Geelen, A., … de Vries, J. H. M. (2017). Evaluation of dietary intake assessed by the Dutch self-administered web-based dietary 24-h recall tool (Compl-eat) against interviewer-administered telephone-based 24-h recalls. *Journal of Nutritional Science, 6*, Article e49. https://doi.org/10.1017/jns.2017.45

Mela, D. J., & Risso, D. (2024). Does sweetness exposure drive "sweet tooth"? *The British Journal of Nutrition, 131*(11), 1934–1944. https://doi.org/10.1017/S0007114524000485

Methven, L., Xiao, C., Cai, M., & Prescott, J. (2016). Rejection thresholds (RjT) of sweet likers and dislikers. *Food Quality and Preference, 52*, 74–80. https://doi.org/10.1016/j.foodqual.2016.03.012

Mintz, S. W. (1985). *Sweetness and power : The place of sugar in modern history*.

Papantoni, A., Shearrer, G. E., Sadler, J. R., Stice, E., & Burger, K. S. (2021). Longitudinal associations between taste sensitivity, taste liking, dietary intake and BMI in adolescents. *Frontiers in Psychology, 12*, Article 597704. https://doi.org/10.3389/fpsyg.2021.597704

Popkin, B. M., & Hawkes, C. (2016). Sweetening of the global diet, particularly beverages: Patterns, trends, and policy responses. *The Lancet Diabetes and Endocrinology, 4*(2), 174–186. https://doi.org/10.1016/S2213-8587(15)00419-2

Ravelli, M. N., & Schoeller, D. A. (2020). Traditional self-reported dietary instruments are prone to inaccuracies and new approaches are needed. *Frontiers in Nutrition, 7*. https://doi.org/10.3389/fnut.2020.00090

RIVM. (2019). The Dutch food composition database - NEVO-online versie 2019/6.0. Retrieved from: https://nevo-online.rivm.nl.

RIVM. (2021). What does the Netherlands eat and drink?. Retrieved from: https://www.wateetnederland.nl/ accessed July 9 2024.

RIVM. (2023). The Dutch food composition database - NEVO-online version 2023/8.0. Retrieved from: https://nevo-online.rivm.nl.

Roininen, K., Tuorila, H., Zandstra, E. H., de Graaf, C., Vehkalahti, K., Stubenitsky, K., & D J Mela DJ.. (2001). Differences in health and taste attitudes and reported behaviour among Finnish, Dutch and British consumers: A cross-national validation of the health and taste attitude scales (HTAS). *Appetite, 37*(1), 33–45. https://doi.org/10.1006/appe.2001.0414

Statista. (2023). Share of the population classed as overweight in the Netherlands in 2023. Retrieved from https://www.statista.com/statistics/544060/share-of-the-population-with-overweight-in-the-netherlands/, 14 March, 2025.

Statista. (2024). Revenue of the artificial sweeteners market worldwide from 2019 to 2029 (in million U.S. dollars). Retrived from https://www.statista.com/statistics/1201648/revenue-artificial-sweetener-market-worldwide/, 6 May 2025.

Sung, Y.-T., & Wu, J.-S. (2018). The visual analogue scale for rating, ranking and paired-comparison (VAS-RRP): A new technique for psychological measurement. *Behavior Research Methods, 50*(4), 1694–1715. https://doi.org/10.3758/s13428-018-1041-8

Tan, S. Y., & Tucker, R. M. (2019). Sweet taste as a predictor of dietary intake: A systematic review. *Nutrients, 11*(1). https://doi.org/10.3390/nu11010094

Tasevska, N. (2015). Urinary Sugars–A Biomarker of Total Sugars Intake. *Nutrients, 7*(7), 5816–5833. https://doi.org/10.3390/nu7075255

US Department of Agriculture. (2024). Total sugar consumption worldwide from 2010/2011 to 2024/2025 (in million metric tons). Retrieved from https://www.statista.com/statistics/249681/total-consumption-of-sugar-worldwide/, 5 july 2024.

Van Rossum, C., Fransen, H. P., Verkaik-Kloosterman, B.-R., & Ocké, M. C. (2011). *Dutch National Food Consumption Survey 2007–2010. Diet of children and adults 7 to 69 years. RIVM report 350050006*.

Walton, J., Bell, H., Re, R., & Nugent, A. P. (2023). Current perspectives on global sugar consumption: Definitions, recommendations, population intakes, challenges and future direction. *Nutrition Research Reviews, 36*(1), 1–22. https://doi.org/10.1017/S095442242100024X

World Health Organization. (2023). WHO advises not to use non-sugar sweeteners for weight control in newly released guideline. Retrieved from https://www.who.int/news/item/15-05-2023-who-advises-not-to-use-non-sugar-sweeteners-for-weight-control-in-newly-released-guideline, accessed on July 07 2023.