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Article

Published Version

Giles, H., Bull, S. P. ORCID: https://orcid.org/0000-0001-5129-1731, Lignou, S. ORCID: https://orcid.org/0000-0001-6971-2258, Gallagher, J., Faka, M. and Methven, L. (2025) Analysing TCATA citation proportions as a tool to optimise temporal vocabulary selection: a case study of whey protein model beverages. Food Quality and Preference, 133. 105628. ISSN 1873-6343 doi: 10.1016/j.foodqual.2025.105628 Available at https://centaur.reading.ac.uk/125107/

To link to this article DOI: http://dx.doi.org/10.1016/j.foodqual.2025.105628

Publisher: Elsevier

Food Quality and Preference 133 (2025) 105628

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Analysing TCATA citation proportions as a tool to optimise temporal vocabulary selection: a case study of whey protein model beverages☆

Holly Giles [a], Stephanie P. Bull [a], Stella Lignou [a], Joe Gallagher [b], Marianthi Faka [c], Lisa Methven [a,*]

[a] Department of Food and Nutritional Sciences, University of Reading, Whiteknights, Reading, RG6 6AP, United Kingdom
[b] Institute of Biological, Environmental & Rural Sciences, Aberystwyth University, Plas Gogerddan, Aberystwyth, Ceredigion, SY23 3EE, United Kingdom
[c] Volac Whey Nutrition Ltd, 50 Fishers Lane, Orwell, Royston, Hertfordshire, SG8 5QX, United Kingdom

ARTICLE INFO

Keywords:
Temporal
Sequential
TCATA
Whey protein
Sensory

ABSTRACT

Sequential profiling is used to assess the temporal variability of attribute intensity perception with repeated consumption; this is insightful for attributes which build-up with repeated consumption, such as mouthdrying in whey protein beverages. It is common for researchers to select attributes for use in sequential tests from the vocabulary lists of descriptive sensory profiling with limited justification being provided. It was hypothesised that Temporal Check All That Apply (TCATA) can be used as an effective and objective technique to select relevant vocabulary. This was investigated using model whey protein beverages containing 10 % whey protein isolate powder with a trained sensory panel and comparing the proportion of citations at regular time intervals across the assessment window. The proportion of panellists selecting an attribute was used to represent panel confidence in the attribute's applicability. Using a consensus vocabulary for TCATA, mouthdrying was selected by 58 % of panellists at 30 s and 71 % at 60 s relative to consumption, identifying this attribute as relevant for temporal investigations. Sweetness was selected by fewer than 10 % of panellists throughout the assessment window. In sequential profiling, mouthdrying significantly increased over time whereas sweetness did not, confirming TCATA as an effective vocabulary selector in this context. The results demonstrate that TCATA can be used to ensure the unbiased selection of relevant attributes to be investigated in subsequent temporal intensity methods. The use of citation proportions can elucidate additional information from TCATA data surrounding the applicability of attributes and panel confidence.

1. Introduction

1.1. The need for temporal sensory methods

Traditional sensory profiling methods involve panellists scoring attributes after a single tasting. However, it is recognised that this cannot fully measure sensory experiences due to changes that occur during mastication, bolus formation and oral processing (Visalli & Galmarini, 2022). In addition to changes occurring in the mouth, the sensory properties of foods and drinks change with consecutive consumption of bites/sips contributing towards a full portion (Visalli & Galmarini, 2022). Temporal sensory methods have been developed to address this dimension to sensory perception. It has been suggested that by considering temporal changes these methods are more realistic and representative of the consumers' experience (Esmerino et al., 2017). There are numerous sensory methods used for this purpose, summarised in a scoping review by Visalli and Galmarini (2022). As with all sensory research, the methodological choice of temporal sensory test involves a compromise between temporal resolution, descriptive and discriminative capacity, validity, complexity, and reliability (Visalli, Galmarini, & Schlich, 2023). An example of this is the number of sensory attributes to be investigated: single and dual attribute time intensity (TI) tests are able to report on the varying intensity of one or two attributes, respectively, over time. Recording only one attribute at a time significantly impacts results, as shown through the "halo-dumping" effect whereby any differences perceived are attributed to the attributes being assessed

☆ This article is part of a Special issue entitled: 'EuroSense 2024' published in Food Quality and Preference.

* Corresponding author at: Department of Food and Nutritional Sciences, University of Reading, Whiteknights, Reading, RG6 6AP, United Kingdom.
E-mail addresses: h.giles@pgr.reading.ac.uk (H. Giles), stephanie.bull@reading.ac.uk (S.P. Bull), s.lignou@reading.ac.uk (S. Lignou), jbg@aber.ac.uk (J. Gallagher), marianthi.faka@volactive.com (M. Faka), l.methven@reading.ac.uk (L. Methven).

https://doi.org/10.1016/j.foodqual.2025.105628
Received 17 December 2024; Received in revised form 18 June 2025; Accepted 27 June 2025
Available online 29 June 2025

(Clark & Lawless, 1994). Additionally, it increases the likelihood of attributes that contribute to the sensory experience being omitted due to methodological restrictions. Other limitations include the difficulty of assessing the intensity of multiple attributes continuously over time, meaning that dual- and multi-attribute time intensity methods have not been widely implemented (Visalli & Galmarini, 2022).

1.2. Comparison of temporal sensory methodologies

The use of alternative temporal sensory methodologies has become increasingly common as a means to address the limitations of time intensity methods (Esmerino et al., 2017). Temporal Dominance of Sensations (TDS) was introduced as a method to capture which sensations were dominant over the consumption period, rather than rating intensity over time (Schlich, 2017). This method allowed multiple attributes to be assessed simultaneously, with one dominant attribute being selected by each panellist at any time. Later, the Temporal Check All That Apply (TCATA) method was introduced, where panellists were asked to register the presence or absence of multiple attributes over time, as a temporal modification to the Check All That Apply (CATA) method (Castura, Antúnez, Giménez, & Ares, 2016). A detailed description of the dynamic sensory profile of products during consumption was provided by TCATA, as panellists could report on all attributes they were experiencing (Ares et al., 2016). This method may provide a more rounded profile, as is not based on dominance; however, conflicting evidence has been found regarding its simplicity when compared with TDS. TCATA has been reported to have higher statistical power, suggesting a higher discriminative ability (Meyners, 2020). This may indicate that TCATA is simpler for panellists to perform, as they are required to select or deselect all attributes they perceive over time, rather than deciding which is the most dominant, as is the case with TDS. Regardless of simplicity, multiple studies have concluded that TCATA provides more detail about flavour and texture perception than TDS (Esmerino et al., 2017; Nguyen et al., 2018). However, TCATA requires more analytical steps to generate meaningful data compared with TDS, such as considering the chance probability of selecting both individual and multiple attributes, an aspect often overlooked in discussions on this technique (Meyners & Castura, 2018). Overall, TCATA has gained widespread acceptance and is commonly used by both consumers and trained panellists (Ares et al., 2016).

One limitation of TCATA is that intensity information is omitted, and as a result, analysis methods often rely on comparing the duration of attribute selection as well as attribute onsets and offsets (Dietz et al., 2022). To address this limitation, sequential profiling has been utilised, where the progressive profile of 5–7 attributes is investigated through consecutive tastings at regimented time intervals. This method was adapted for use in drinks by Methven et al. (2010) when the sensory profile of oral nutritional supplements (ONS) across 5 attributes was investigated. The ideal number of attributes for sequential profiling will be context specific, but researchers have impressed the importance of not overwhelming participants with too many attributes (Pineau et al., 2012). Typically, publications have included 5–7 attributes for sequential profiling, with good results recorded from panellists (Methven et al., 2010), indicating that this number is appropriate. In sequential profiling, a low number of attributes (taste, flavour and/or mouthfeel) are scored by participants immediately after tasting and after a 30 s delay to account for after-taste, with the process being repeated for 8–10 consecutive sips to show the evolution of taste and flavour with repeated consumption (Methven et al., 2010). This method enables collection of intensity data for a range of attributes overcoming many of the limitations associated with TI, TDS and TCATA. In this earlier study using ONS, it was shown that attributes including soya milk flavour, metallic taste and mouthdrying significantly increased with consumption ($p < 0.002$), negatively impacting liking (Methven et al., 2010). This highlights the need for sequential profiling as the importance of these attributes may have been missed in static profiling, and they can provide additional information to research and development teams trying to minimise or optimise the intensity of several attributes over time.

A previous investigation of these temporal sensory methodologies by Esmerino et al. (2017) compared TDS, TCATA and progressive profiling (a single sip version of sequential profiling) of fermented dairy drinks and found good agreement between the three methods. The study showed that the citation proportion of TCATA had a close relationship with the intensities determined by progressive profiling (Esmerino et al., 2017). However, this was completed using a single-sip tasting experience by consumers, meaning that the relationship between these methods in a multi-sip context is not known. The current study will build on this work in a multi-sip context to further understand the relationships between these methodologies.

1.3. The potential for researcher bias within temporal sensory studies

For the majority of sensory methodologies, there are clear guidelines for the selection of attributes, such as using group discussions to generate a consensus vocabulary in quantitative descriptive analysis (QDA™) detailed in the ISO standard 13,299 (ISO, 2016). However, the low number of attributes used for temporal methods means that truncation of the consensus vocabulary is required. For this, guidelines are limited, and in the literature it is often unclear what rationale has been used for attribute selection. A recent review quantified the method by which attributes had been selected for temporal studies; in 40 % of studies attributes were chosen by panellists, 15 % by the researcher, 15 % from references to the literature, 15 % by an alternative panel, and in 15 % of articles the basis for the choice was not reported (Visalli & Galmarini, 2024). This highlights a key limitation in temporal sensory studies and suggests practices could be optimised going forward.

An example of this in practice can be seen when sequential profiling builds on standard profiling: here it is often unclear how the shortlist of attributes have been selected for inclusion from the extensive consensus vocabulary, with the attribute number decreasing from 25 to 30 to 5–7 based on static profiling data alone such as in the study of Bull et al. (2017). Sequential profiling can also be presented in isolation, as in the work of Olatujoye et al. (2020); here, minimal details were given on the generation of attributes and there was little consideration to their relevance for temporal investigations (Olatujoye et al., 2020). In both of these cases, it is likely that the selection of attributes for sequential profiling was influenced by the study aims, panellist discussions, and use of the current literature. However, as there is no standardised, objective methodology to oversee this process, it should also be considered that this subjective method is open to bias, including influence by dominant panellists or by the researcher guiding panellists' choices. A recent review on temporal methods concluded that temporal measurements are yet to reach methodological maturity, supporting that there is scope for optimisation and developments in this field (Visalli & Galmarini, 2024). Research is needed to identify an objective method for attribute shortlisting to reduce the scope for researcher bias in this context and to ensure the relevance and suitability of attributes selected for further temporal investigations.

1.4. The relevance of whey protein as a case study for temporal sensory studies

ONS commonly use whey as a protein source due to its positive bioavailability and impact on muscle synthesis (Cereda et al., 2022). Numerous studies have completed sensory profiling on these products, where it has been found that negative characteristics limit consumer acceptance (Norton et al., 2020) and consumption (Jobse et al., 2015). Of these, it is the perception of mouthdrying that has been reported as a key driver for disliking of whey protein-fortified products (Zhang et al., 2020). The mechanisms responsible for whey-protein associated mouthdrying are not fully understood (Giles et al., 2024), but have been shown to significantly build-up with repeated consumption (Bull et al., 2017), highlighting the relevance of these products for temporal investigations, including sequential profiling. Supporting this is the standard profiling previously completed on whey protein model beverages (Giles et al., 2025). In this study, significant differences between samples were only reported for mushroom flavour ($p = 0.01$), mouthcoating ($p = 0.03$) and smoothness ($p = 0.012$). The omission of a difference in mouthdrying perception was suggested by the authors to be a reflection of the single-sip profiling methodology, justifying the need for temporal studies on these samples (Giles et al., 2025). This demonstrates the suitability of whey protein model beverages as a case study to investigate temporal sensory methods as its sensory profile is known to vary with repeated consumption.

1.5. Aims & hypotheses

The authors propose that there is a gap in sensory methodology for the reliable shortlisting of attributes from an extensive consensus vocabulary for use in subsequent temporal studies, such as sequential profiling, when only a small number of attributes can be assessed. It is hypothesised that analysis of TCATA citation proportions may indicate the temporal experience of an attribute, providing an objective method to identify attributes likely to display temporal variability to be taken forward into sequential profiling. The primary aim of the study was to investigate whether the use of TCATA citation proportions provide a robust method for attribute selection for use in sequential profiling of whey protein isolate (WPI) model beverages.

It is accepted by the authors that the relevant attributes will be product-specific: this was best described by Meyners and Castura (2018) in their definition of the term “product space” where all test results depend on the set of products used in the study as these define the product space. For these beverages it was hypothesised that mouthdrying would significantly build up over time during TCATA and with repeated consumption in sequential profiling, as seen in Bull et al. (2017). By contrast, sweetness has previously shown no changes across a sequential profile (Methven et al., 2010), thus it was hypothesised that sweetness perception would not show significant temporal variability in either method. It was not anticipated how other sensory attributes would be influenced as there is limited previous temporal research of other attributes in these whey models. It was hypothesised that TCATA could identify attributes likely to display temporal variability which can subsequently be taken forward in the design of temporal intensity sensory studies to increase the relevance of results.

The secondary aim of this study was to investigate the use of TCATA as a tool to identify appropriate attributes for further investigation via sequential profiling. TCATA curves are traditionally used to compare different products, as seen in Dietz et al. (2022), whereas the aim of this study was to use TCATA citation proportions as a means to compare selection within the same product at different timepoints. It was hypothesised that this would provide a preliminary indication of the temporal variability of attributes, which cannot be achieved through analysis of the duration of attribute selection, and facilitate the use of TCATA as a tool for attribute selection for use in sequential profiling, aiding scientific understanding and sensory practice.

2. Methodology

2.1. Materials

Whey protein isolate (WPI) was provided by Volac Whey Nutrition Ltd. (Hertfordshire, UK). Maltodextrin, xanthan gum (XG) and guar gum (GG) were sourced from Special Ingredients (Chesterfield, UK). Carr’s water crackers were sourced from McVities (Middlesex, UK).

2.2. Sample preparation

Whey protein model beverages were prepared as 10 % WPI suspensions. The WPI had been spray dried with different levels of maltodextrin, XG and GG: this methodology for co-spray drying has been detailed previously (Giles et al., 2025). The final levels present in suspensions are detailed in Table 1. 10 % WPI suspensions were prepared using 25 g (± 0.5 g) powder and making it up to 250 mL using bottled water (Harrogate Spring Water, Harrogate, North Yorkshire, UK). The mixture was stirred using a magnetic stirrer (CAMLAB Limited, Cambridge, UK) for 60 min at room temperature (19 ± 2 °C). Samples were refrigerated overnight (16–20 h) prior to use and analysed within 24 h of production. Further details of sample preparation were given in Giles et al. (2025).

2.3. Temporal check all that apply (TCATA)

A screened and trained sensory panel (n = 12; females 11, male 1) participated in this study, based at the MMR Sensory Science Centre in the UK (MMR Research Worldwide Ltd., Wokingham, UK). All panellists had a minimum of 16 months experience: the panel was given further training on mouthfeel attributes used for WPI profiling (minimum 3 h), before evaluating 10 % w/v WPI suspensions using TCATA. TCATA was completed with the consensus vocabulary from the previous “static” profiling method (Giles et al., 2025): 20 of these attributes addressed taste and flavour ($n = 8$), mouthfeel ($n = 5$) and after-effect ($n = 7$) so were eligible for inclusion. Previous research has shown that 10–15 attributes can be assessed simultaneously in TCATA whilst ensuring adequate discrimination between samples (Jaeger et al., 2018). Descriptors and references provided for attributes were detailed in Giles et al. (2025). WPI samples were evaluated in duplicate according to a balanced design in transparent cups (30 mL), with 10 mL of suspension being added to each cup. Panellists drank the full contents of the first cup and immediately started the timer within the sensory software, the second cup was consumed after 30 s: the experimental procedure is illustrated in Fig. 1. Multi-sip evaluations have been shown to be more representative of typical consumption experiences than single-sip profiling (Weerawarna et al., 2021). In the current study, it was not considered appropriate to have a high number of sips, as the purpose was to demonstrate the use of TCATA as a stepping-stone methodology for sequential profiling: thus, an intermediary sip number of two was selected to limit panellist confusion, whilst giving an preliminary indication of potential build-up. Throughout the 90 s assessment period, panellists were instructed to check attributes as they became relevant, and deselect when the attribute no longer applied (Fig. 1A). Panellists’ training included instruction on oral processing and how to consume the samples, to minimise excessive movement within the mouth and to swallow near-immediately after consumption; thus the variation in sipping time was assumed to be negligible. Low salt crackers and warm filtered tap water were provided as palate cleansers between samples during an enforced break (2 min). Evaluation was carried out under artificial daylight in individual booths. This was completed for the five

Table 1
Respective levels of whey protein isolate (WPI), maltodextrin (M), xanthan gum (XG) and/or guar gum (GG) that were included in final 10 % w/v suspensions. All samples were tested using static sensory profiling. The samples were subsequently assessed using Temporal Check All That Apply and sequential profiling. Adapted from (Giles et al., 2025).

Suspension	Whey protein isolate (%)	Maltodextrin (%)	Xanthan gum (%)	Guar gum (%)
WPI	10	–	–	–
WPI/M	9.52	0.48	–	–
WPI/XG	9.97	–	0.03	–
WPI/GG	9.95	–	–	0.05
WPI/M/GG	9.47	0.48	–	0.05

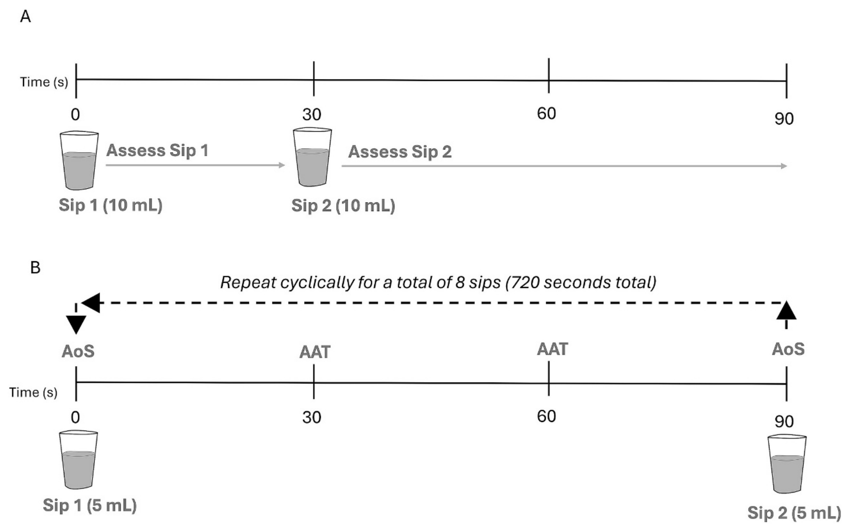

Fig. 1. Overview of the sip tasting protocol used for: [A] the Temporal Check All That Apply methodology with continuous sensory assessment; [B] the sequential profiling methodology using Assess on Sip (AoS) and Assess Aftertaste (AAT) instructions. This was performed by trained sensory panellists to assess 10 % *w/v* suspensions of whey protein isolate combined with maltodextrin, xanthan gum, and/or guar gum.

samples presented in Table 1. Sensory questions were presented, and data collected, on Compusense (cloud version, Ontario, Canada).

2.4. Sequential profiling

The same trained sensory panel evaluated samples using sequential profiling, following the methodology described in Methven et al. (2010). Suspensions were presented in 8 transparent cups (30 mL), with 5 mL of suspension being added to each cup. This was selected to total 40 mL for each sample, allowing the assessment of two samples during each tasting session: this is consistent with consumer behaviour where 37 % of a typical 220 mL portion is consumed, giving an average total daily consumption of 80 mL (Gosney, 2003; Methven et al., 2010). Panellists consumed the first sample and immediately scored the attributes. The attributes were scored for after-effect after 30 s and again after a further 30 s. The next cup was consumed 90 s after the first. This was repeated cyclically until a total of 8 cups had been consumed: the experimental methodology is illustrated in Fig. 1B. Due to the increased complexity of this methodology compared with TCATA, this was completed in an open room with the panel leader instructing panellists when to consume and score the samples: this environment was chosen to enable panellists' actions to be monitored and timings to be tightly controlled, reducing the risk of panellist error. Instructions integrated into software can be disrupted by minor device connection or attention discrepancies, whereas using manual instructions alongside the software ensured all panellists consumed and/or scored within a 3 s window, increasing reliability. Panellists were instructed to avoid eye-contact and maintain a neutral expression throughout. Attributes for assessment were selected based on the TCATA results, leading to limited mouthfeel ($n = 4$) and taste ($n = 2$) attributes being scored. Samples were evaluated in duplicate according to a balanced design. Carr's water crackers and warm filtered tap water were provided as palate cleansers between samples during an enforced break (2 min). Evaluation was carried out under artificial daylight. Variation in sipping time was negligible due to training on oral processing methods to consume the samples consistently. This method was completed for the samples presented in Table 1. Sensory questions were presented, and data collected, on Compusense (cloud version, Ontario, Canada).

2.5. Method validation of sequential profiling

Using the same methodology as previously described (section 2.4), sequential profiling was completed for 10 % *w/v* WPI suspensions in a blinded and unblinded manner. For the unblinded protocol, panellists were aware that each cup contained the same sample and were asked to complete the sequential profiling protocol. For the blinded protocol, panellists were told that each of the 8 cups contained a different sample and were asked to complete the sequential profiling protocol. This was completed for WPI only: suspensions including maltodextrin, XG and GG were not required for method validation. Sensory questions were presented, and data collected, on Compusense (cloud version, Ontario, Canada).

2.6. Statistical analysis

Static profiling data was analysed using Senpaq (Kent, UK): two-way ANOVA was used where the sample was the fixed effect and the panellists the random effects, with both effects tested against the sample by panellist interaction. Tukey HSD tests were used for multiple pairwise comparisons to assess significance between samples, at a significance value of $p < 0.05$. The duration of attribute selection for TCATA was also analysed in this way.

TCATA data was initially analysed using the TCATA package on XLSTAT (version 2021.5.1) to compare product attribute selection using a significance value of $p < 0.05$ for comparisons in Chi-squared. This was used to generate TCATA curves (Supplementary Fig. S1) and attribute citation proportion graphs (Supplementary Fig. S2). Secondary analysis for TCATA was completed on the data as an unfolded binary data matrix with "1"s to indicate attribute selection, and "0"s to indicate attribute de-selection by a given panellist at each second of the assessment window. Meyners and Castura (2018) previously suggested the possibility of analysing TCATA data time point by time point, using similar tools as for classical CATA. To compare the proportion of panellists selecting each attribute over time, and due to the binary nature of the matrix, the proportion of panellists selecting an attribute was determined for 0 s, 30 s, 60 s and 90 s. These values were compared qualitatively using a decision flow chart (Fig. 2). It was not possible to use Cochran's Q test for this purpose, as is commonly done for CATA data, due to the strong correlations existing between the timepoints, meaning the test assumptions are not met. Instead, the chance probability of an attribute being selected was calculated as the average number of attributes selected per panellist at a given time, divided by the number of attributes. This was completed at 30 s, 60 s and 90 s to determine if attributes were selected more than would be expected by chance. Time

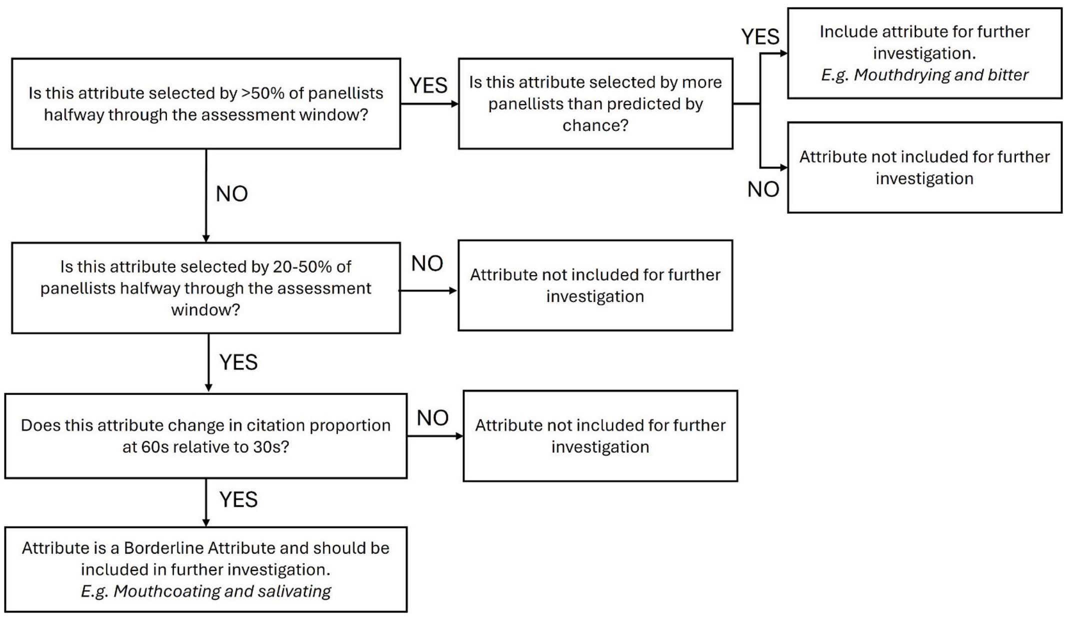

Fig. 2. Flow chart used for the systematic selection of attributes for further sensory investigations using citation proportion data from Temporal Check All That Apply assessment of whey protein model beverages.

standardisation of data was not required as the study used trained panellists with a tasting protocol containing specific timepoints for sipping, a fixed start and end point, and specific instructions for oral processing (Dietz et al., 2022). It has been previously reported that statistical time standardisation provides limited insights on multiple intake data, with attributes of a short duration being lost, (Dietz et al., 2022), so it was not appropriate for use in this study.

Sequential profiling data was analysed using IBM SPSS Statistics (version 21.0) to carry out three-way repeated measures ANOVA (RM-ANOVA) on the sequential profiling data using sample ($n = 5$), panellists ($n = 12$), and repeated consumption ($n = 8$) as explanatory variables. Multiple pairwise comparisons were carried out using Bonferroni confidence interval adjustment and significance value of $p < 0.05$. For the method validation stage, the average mouthdrying perception was normalised based on the first sip to account for the random difference in sip 1 between the two tasting protocols. We anticipate that the differences in sip 1 are due to the protocols being performed on different days, meaning some variation is to be expected. The data was then processed using SPSS statistics in same way as described above.

3. Results & discussion

Building on the standard profiling completed by the trained sensory panel on these products (Giles et al., 2025), TCATA was completed for 13 attributes covering taste, flavour, mouthfeel and after-effect. The traditional method to visualise this data is through TCATA curves, as demonstrated by Castura et al., 2016. This analysis was performed for all five products, with data for WPI and WPI + M being included in Supplementary Fig. S1. Here it is shown that for both products the citation proportions for some attributes appear to decrease over time, such as powdered milk, whereas for others they appear to increase over time, such as mouthdrying. However, as seen in S1, readability is poor when a high number of attributes are being investigated. This can be overcome by using TCATA difference curves (Castura et al., 2016), which facilitate statistical comparisons between citation proportions for each product. However, in the current study the focus was on attributes which may vary in selection within a product over time, rather than the comparison between products.

3.1. Duration of attribute selection during TCATA

TCATA data was analysed by comparing the duration of attribute selection for each product (Table 2) where a significant difference in selection duration was observed between the five samples for mushroom ($p = 0.0056$), mouthcoating ($p = 0.0303$), and slippery ($p = 0.0075$) perception. No other attributes showed a significant difference in duration of selection. Mushroom and mouthcoating were previously identified as significant using the same panel in static profiling (Giles et al., 2025), suggesting that TCATA duration data provide comparable information for these attributes in this context. However, slippery perception was not previously identified as different in static profiling:

Table 2
Average duration (s) of attribute selection for Temporal Check All That Apply assessment of 10 % *w/v* suspensions of whey protein isolate (WPI) combined with maltodextrin (M), xanthan gum (XG) and/or guar gum (GG).

Attribute	Average duration of attribute selection (s) #					Variation in attribute selection duration (p-value) *
	WPI	WPI/M	WPI/XG	WPI/GG	WPI/M/GG	
Bitter	36.5	35.0	27.3	29.7	19.6	0.08
Umami	5.6	11.9	10.6	7.4	4.5	0.19
Sweet	5.2	3.6	5.1	7.8	6.2	0.68
Metallic	26.2	26.7	25.3	30.1	23.7	0.81
Powdered milk	35.8	26.2	34.9	32.6	41.4	0.12
Creamy	13.8	11.5	14.5	8.0	18.2	0.28
Cheesey	12.9	17.4	27.3	20.9	17.7	0.16
Mushroom	5.7^{B}	19.0^{A}	28.2^{A}	22.1^{A}	17.5^{A}	0.01 *
Mouthcoating	17.0^{BCE}	14.8^{C}	19.8^{ABC}	25.0^{AB}	26.6^{A}	0.03 *
Mouthdrying	47.4	42.5	44.5	47.3	53.6	0.43
Slippery	5.8^{B}	4.3^{B}	10.4^{AB}	16.6^{A}	7.0^{B}	0.01 *
Smoothness	4.3	2.8	3.4	4.3	1.0	0.78
Salivating	20.2	22.2	18.7	15.6	15.2	0.48

* Denotes significance ($p < 0.05$)
\# Pair-wise comparisons (post-hoc Tukey test) shown in superscript where sample means not sharing a common letter for an attribute were significantly different.

for duration data the addition of guar gum was associated with a significantly higher duration of slipperiness selection ($p = 0.0075$). This may hint at the additional data provided by temporal methods such as TCATA. Differences may have been omitted in static profiling if the initial intensity is the same, but if the attribute is applicable for longer this will influence the sensory experience. This highlights the need for multiple sensory methodologies to fully understand the sensory profile of products.

There were no significant differences when comparing the average duration of mouthdrying selection between samples ($p = 0.43$). An initial interpretation of this result is that the addition of polysaccharides had no effect on mouthdrying of WPI beverages, which is in keeping with the results of static profiling (Giles et al., 2025). However, there is debate within the literature about the reliability of duration data: it has been reported that panellists focus more on continuously selecting than on deselecting terms, meaning attributes may remain selected for longer than is applicable (Ares et al., 2016; Rizo et al., 2020). Duration may not be a reliable comparative measure due to difficulties in determining the exact moment to deselect (Visalli et al., 2024): it is likely that this is especially applicable when considering mouthfeel attributes. To address this, the method has been adapted in TCATA Fading, where attributes are steadily deselected automatically and need to be reselected if appropriate. However, current work on this method has focused on solid products, meaning its suitability for liquids is not known (Ares et al., 2016). Whilst the risk of extended selection was minimised via thorough panellist training, it is possible that duration was not an appropriate measure for comparison due to assessment difficulties.

In addition, a limitation in the use of duration data in isolation is that it does not consider intensity or temporal differences in perception as it uses time as the dependent variable. Whilst it cannot be assumed to correlate with intensity, it was noted that bitter, powdered milk and mouthdrying perception were all selected for over 35 s for WPI, suggesting that these attributes significantly impact the sensory profile of the products. Intensity has previously been shown to significantly increase with repeated consumption for mouthdrying (Bull et al., 2017), perhaps suggesting that duration data from TCATA may not be able to fully represent the sensory experience of this attribute. Previous studies have suggested that TCATA should be considered as an exploratory data analysis method and that the direct comparisons of data sets are inappropriate (Béno et al., 2023). However, the authors suggest that further conclusions can be drawn from TCATA data by comparing the proportion of panellists selecting an attribute at given time points, to provide a measure of confidence in the applicability of the attribute. This additional analytical method may have the potential to provide supplementary information from TCATA data for use in subsequent sensory investigations.

3.2. Citation proportions of attribute selection over time using TCATA

An additional method to investigate TCATA data is suggested through the comparison of citation proportions, defined as the proportion of panellists selecting an attribute at given time intervals during the assessment window. This was completed for all five samples (data not shown), however this manuscript focuses on the first sample (untreated WPI) as this was taken forward for sequential profiling. The citation proportion curves separated by attributes are shown in Supplementary Fig. S2: this demonstrates the ability to visualise the proportion of panellists selecting an attribute across the assessment window. This gives an indication of attribute selection over time, however the subjective nature of drawing conclusions from these graphs means that it is insufficient for attribute selection purposes. The objective of this study was to develop an objective, reliable method for attribute selection, which cannot be obtained through visualisation alone.

To address this, the data was visualised as an unfolded data matrix to calculate the proportion of panellists selecting an attribute at 30 s time intervals. This allowed the citation proportions to be compared across the assessment period (Fig. 3). The citation percentages for each timepoint are given in Supplementary Table S3. A systematic process was then applied to this data (Fig. 2) to identify attributes anticipated to show temporal variability and meriting further investigation.

The first stage of this systematic selection was the identification of attributes which were selected by over 50 % of the panellists halfway through the assessment window (60 s). This was seen for bitterness (50 %) and mouthdrying (70.8 %). To understand if this selection proportion was meaningful, the number of panellists expected to select an attribute by chance (chance probability) was calculated. The need for chance probability to be considered was previously discussed by Meyners and Castura (2018). At 60 s the mean number of attributes selected per panellist was 2.9, therefore the number of panellists anticipated to choose any particular attribute by chance was 4.4. Bitterness and mouthdrying were selected by more panellists than indicated by the chance probability ($n = 6$ and $n = 8.5$, respectively) and both displayed an increase of more than 10 % in the proportion of citations at 60 s relative to 30 s (Table 3). This suggests that these attributes were contributing substantially to the sensory profile of the product and merit further investigation. As a result, both attributes were taken forward for sequential profiling. Previous studies have reported a close relationship between the citation proportion in TCATA and intensity data in progressive profiling (Esmerino et al., 2017), meaning this may correlate with a time-associated increase in intensity. It is likely that either mouthdrying and bitterness increased in intensity over time, or that more panellists were aware of these sensations at 60 s relative to 30 s. This interpretation supports Beno, Nicolle and Visalli et al. (2023), who suggested that the citation proportion reflects the level of panel confidence in the applicability of attributes at a given time. This temporal relationship is consistent with existing research for mouthdrying with regards to build-up (Bull et al., 2022). Investigating the citation proportions for the most highly selected attributes optimised the selection process for the truncation of attributes.

In addition, some attributes were identified by 20–50 % of panellists, indicating that they may contribute to the temporal sensory profile in a more subtle way. Of these, cheesey, mushroom, powdered milk and salivating all displayed a small increase in selection at 60 s relative to 30 s (Table 3). These were defined by the researchers as "borderline attributes" where the nature and strength of the temporal relationship was unknown. To assess this temporal variation, salivating was selected for further investigation through sequential profiling. Contrastingly, mouthcoating showed a reduction in proportional selection across these two timepoints, so it was again included in sequential profiling as a borderline attribute to investigate any effect this might have on temporal intensity. Sweetness and slipperiness were selected by fewer than 10 % of panellists (1 panellist) at 30 s and 60 s (Table 3). Using the proposed method, this would be evidence for not selecting an attribute as relevant for further temporal investigations, such as sequential profiling. However, they were progressed to sequential profiling to investigate the ability of citation proportions to select attributes. Using this data, it could be hypothesised that bitterness and mouthdrying would show significant temporal variation in sequential profiling, and that sweetness and slipperiness would not. It was unknown how salivating or mouthcoating would respond in this format.

Whilst the simplicity of TCATA means it can be used with consumers to understand the sensory profile of products over time, in this current study trained panellists were required for the process of attribute selection, ensuring a detailed and consensus understanding of attributes. Whilst the assessment of the data using citation proportions is predominantly qualitative, this practice of descriptive statistics is more systematic than current practices and may be a reliable method to highlight attributes of relevance. It has been noted that the absence of an attribute will not be highlighted by TCATA, despite potentially being important for the overall sensory profile (Meyners & Castura, 2018). This supports our conclusion that no sensory method should be used in isolation: instead TCATA data (both duration and citation proportions)

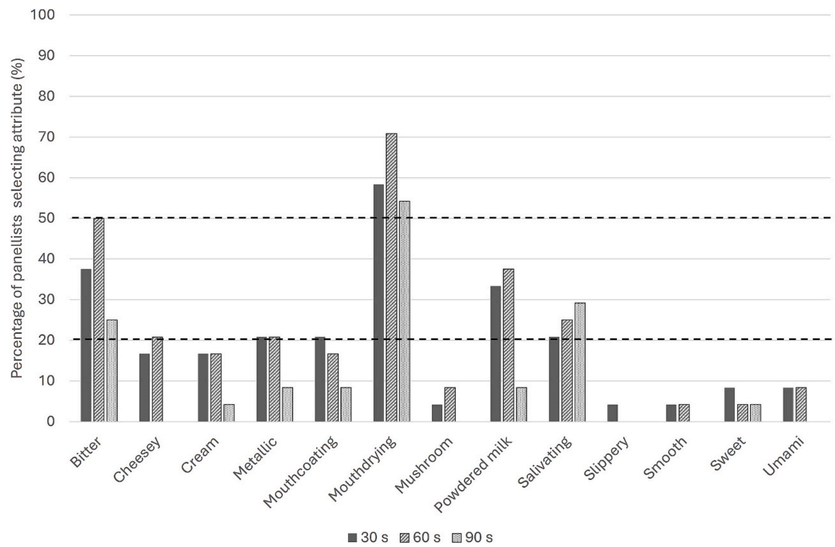

Fig. 3. Proportion (%) of trained sensory panellists selecting an attribute at 30 s, 60 s and 90 s during the Temporal Check All That Apply analysis of 10 % *w/v* whey protein isolate suspensions. Dashed lines used to show 20 % and 50 % of citation proportions: these cut-offs were used in the selection of attributes.

can be used as a tool for attribute selection for further temporal investigations.

3.3. Sequential profiling using attributes identified through TCATA

From TCATA profiling it was anticipated that mouthdrying and salivating would show temporal changes in intensity, mouthcoating may show such temporal changes, and sweetness would not vary in intensity over time. This was tested through sequential profiling of WPI. Here, mouthdrying perception was shown to significantly increase with repeated consumption ($p < 0.0001$) (Fig. 4A), as anticipated. Over 8 consecutive sips, average mouthdrying intensity increased by 10 points: this is in agreement with Bull et al. (2017), where a similar magnitude of change was reported for whey protein concentrate beverages. This highlights the ability of citation proportion data from TCATA to identify temporal variability for mouthdrying.

Of the "borderline attributes identified by TCATA, salivating did not show a significant increase over time ($p = 0.39$) (Fig. 4B). This indicates that there was no temporal effect on intensity of perceived salivation, however it could also reflect high inter-individual variation for this attribute (section 3.5). Alternatively, the suggested difference between TCATA and sequential profiling may relate to the difference in bolus volumes between the two tests: in TCATA a larger (10 mL compared with 5 mL) volume was used which may have led to the borderline difference observed. By contrast, mouthcoating was shown to significantly increase over time ($p = 0.0026$) (Fig. 4D). This advocates for the inclusion of these "borderline attributes" in sequential profiling and justifies the use of TCATA as a stepping-stone technique to select relevant attributes, rather than as a standalone method, as the significance of these attributes was not fully elucidated from the TCATA. The ability of TCATA to highlight these potentially relevant attributes for inclusion in sequential profiling is useful.

Finally, sweetness perception was not anticipated to show temporal variability and indeed in sequential profiling sweetness did not significantly change with repeated consumption ($p = 0.61$) (Fig. 4C). At the sweetness levels tested, this was consistent with the literature (Withers et al., 2016). However, it is noted that sweetness intensity was much lower than mouthdrying, meaning it is possible that sweetness may be temporally influenced at higher levels, in-line with the product-specific relationship of attributes previously discussed (Meyners & Castura, 2018). This highlights the need for vocabulary selection using TCATA to be completed for each study as the suitability of attributes will vary depending on the product being investigated. The addition of TCATA as part of the vocabulary selection for temporal rating methods would increase study time and costs, however, it provides a robust and unbiased approach. The study demonstrates the ability of TCATA to identify attributes likely to display temporal variability and meriting inclusion in subsequent temporal investigations. The differing results shown by TCATA and sequential profiling are detailed in Table 3. These highlight the benefits of using the two techniques together, with TCATA as a vocabulary selector for sequential profiling.

3.4. Method validation of sequential profiling

Panellist behaviour was investigated by comparing a blinded and unblinded protocol for sequential profiling (Fig. 5), as previously completed by Methven et al. (2010). The data from both protocols were normalised by the first sip to show successive differences, and to overcome the potential for random differences between repeats. The two profiles (where panellists were blinded or unblinded to the sequential nature of the sensory test), showed a significant increase in mouthdrying intensity with repeated consumption ($p = 0.004$). There was no significant difference between the two protocols, suggesting that awareness of the sequential nature of consecutive tastings does not significantly influence results. Methven et al. (2010) concluded that whilst panellists may exaggerate the build-up when aware they were completing a sequential profile, the trend was the same irrespective of the blinding protocol. The importance of examining panellist behaviour, prior to concluding on temporal differences, has been emphasised in the literature (Visalli et al., 2023). Overall, by comparing a blinded and unblinded protocol it was shown that psychological predictions were not significantly influencing results, but emphasises the need for method validation stages before making this assumption.

3.5. Potential sources of panellist variability

In addition to validating the method, panellist performance was investigated for sequential profiling (Table 4). Due to the use of an unstructured line scale in this work, it was anticipated that there would be significant panellist variability as a result of panellists using the scale differently. This significant difference was seen for all four attributes ($p < 0.0001$) (Table 4). In addition to variable scale use, it is thought that the low sweetness intensity of the samples may have contributed to variation for this attribute; samples may have been below the threshold

Table 3
Comparison of temporal influence suggested by Temporal Check All That Apply (TCATA) and sequential profiling (SP) for whey protein isolate model beverage (10 % *w/v* suspension).

Attribute	Citation proportion in TCATA	Temporal change in citation proportion in TCATA*	Sequential Profiling (SP)$	Comparison of the two sensory tests$#
Bitter	High	↑	X	TCATA identified attribute for SP, but no temporal effect on intensity#
Cheesey	Low	→	NA	NA
Cream	Low	X	NA	NA
Metallic	Low	X	NA	NA
Mouthcoating	Low	→	↑	TCATA identified borderline attribute for SP, temporal effect on intensity concluded#.
Mouthdrying	High	↑	↑	TCATA identified attribute for SP, temporal effect on intensity concluded#
Mushroom	Low	→	NA	NA
Powdered milk	Low	→	X	TCATA identified borderline attribute for SP, no temporal effect on intensity#
Salivating	Low	→	X	TCATA identified borderline attribute for SP, no temporal effect on intensity#
Slipperiness	Low	X	X	Temporal method not needed#
Smoothness	Low	X	NA	NA
Sweetness	Low	X	X	Temporal method not needed#
Umami	Low	X	NA	NA

* Arrows used to represent an increasing (↑) or moderate (→) change in citation proportion in TCATA. X used to represent no change in citation proportions.

$ *NA used to denote when an attribute was "Not Assessed" using a given methodology.*

Borderline attributes defined as those with low citation proportion displaying a moderate temporal change in TCATA. Conclusions drawn within this product context and may differ between product types.

of sweetness for some panellists, leading to a score of zero. This creates significant variation as panellists appear to be using the scale differently. This is unavoidable for attributes that have a low intensity but are still important for inclusion. The panel displayed good repeatability (data not shown), meaning the results are likely to reflect varying thresholds and can be used in the context of this study.

It is also possible that the variability between panellists for mouthfeel may be the result of inter-individual variation in salivary reflex mechanisms. Previous suggestions for the cause of whey protein-associated mouthdrying include age, gender, and salivary composition and flow rate (Norton et al., 2021), but more research is needed to understand the factors that impact this sensation. With increased understanding of the relevant factors, sources of variation within the panel could be reduced. However, this is not possible with current levels of understanding and highlights the limitations to current research in this area. For the context of this study, there was no significant panellist*sip interaction ($p = 0.97$) so the significant variability is thought to reflect a real variation in mouthdrying perception, which could not be controlled through training.

Similarly the panel variability seen for salivating and mouthcoating perception ($p < 0.0001$) may be reflective of inter-individual panellist variation in the salivatory reflex mechanism: depending on the speed of saliva production, some panellists may have scored a sample as highly salivating as their mouth was full of saliva immediately after tasting, but those with a slower reflex may have scored salivating as low. This may be a result of variations in salivary flow rate which has been previously shown to significantly decrease with age (Norton et al., 2020). It is possible that the decrease in salivary flow rate means that older panellists will score samples as less salivating than younger panellists: this was previously observed in a trained sensory panel using whey protein to assess mouthdrying intensity (Withers et al., 2013). Due to the small size of the panel in the current study, it was not appropriate to investigate the effect of age, however potential differences between panellists may have influenced results. Other sources of variation may include the degree of hydration, medication use, stress and behavioural factors (Dawes, 1987). As such factors show within-individual variation over time, it can be difficult to train a sensory panel to reproducible score attributes such as mouthdrying and salivating. Significant variation emphasises the difficulty in standardising textural perception for attributes such as mouthdrying and salivating, in comparison to taste. Significant variation between panellists has been previously reported for textural assessments of milk-based desserts (Ares et al., 2011), confirming inter-individual variation in textural perception. The authors propose that this variability is not a result of lack of training or poor performance, but instead may represent a real difference between panellists' rate of salivary production in response to a drying stimulus.

4. Conclusion

It was hypothesised that TCATA may be an objective method to select attributes for sequential profiling from an extended consensus vocabulary, improving on current research practices. This method provided additional information from TCATA data that was not elucidated by duration selection alone. Using a model whey protein beverage, TCATA was able to identify mouthdrying as relevant for inclusion in sequential profiling through a high citation proportion and an increase in attribute selection over time. Mouthcoating also reached borderline significance so was chosen for further investigation. Sweetness was not shown to be temporally influenced in TCATA. When investigating these attributes in sequential profiling, mouthdrying and mouthcoating significantly increased over time, whereas sweetness did not, echoing the predictions of TCATA. This research demonstrates the use of TCATA as an objective attribute selector for sequential profiling. No significant differences were found when comparing a blinded and unblinded protocol for sequential profiling. Significant levels of panellist variability were reported for all attributes: the authors propose that variation in mouthdrying and salivating perception may be a result of individual variation in salivary flow rate and the response of salivary production to a drying stimulus, highlighting the difficulty in standardisation for these attributes.

Overall, this study highlights the ability of TCATA to identify attributes that display temporal variability through analysis of citation proportions. Future research should investigate this methodology in different food contexts, as well as the factors that influence mouthdrying and salivating perception of whey protein beverages.

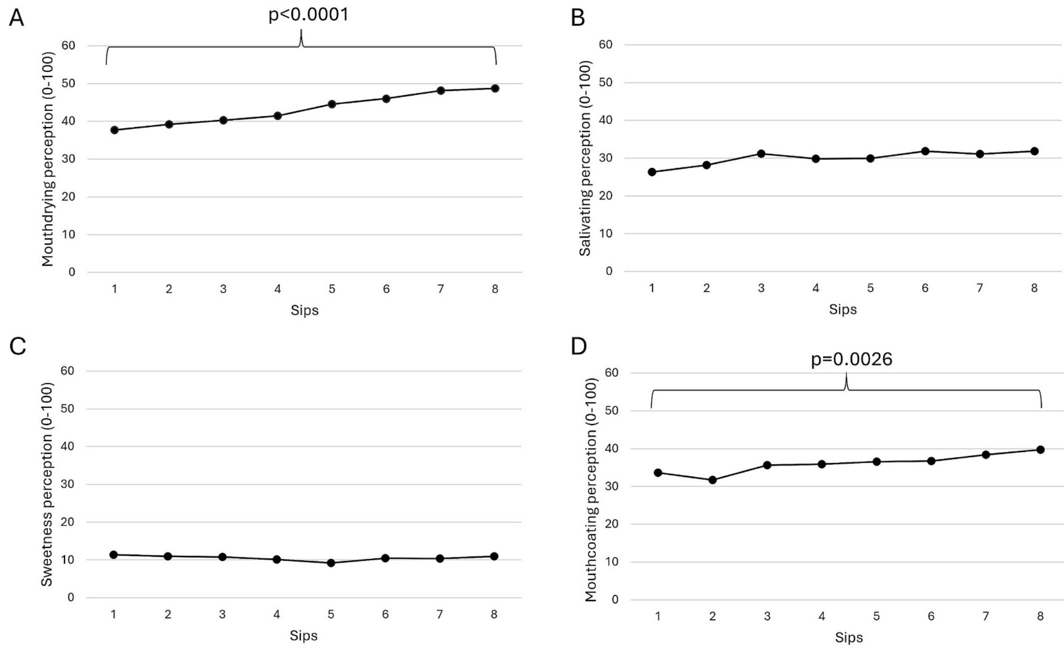

Fig. 4. Average perception score during sequential profiling over 8 consecutive sips of 10 % whey protein isolate suspensions. Attributes shown are: [A] mouth-drying; [B] salivating; [C] sweetness; and [D] mouthcoating. Overall significance value included when $p < 0.05$ and pairwise comparisons shown with letters as assessed using Tukey's post-hoc analysis with a significance value of 0.05.

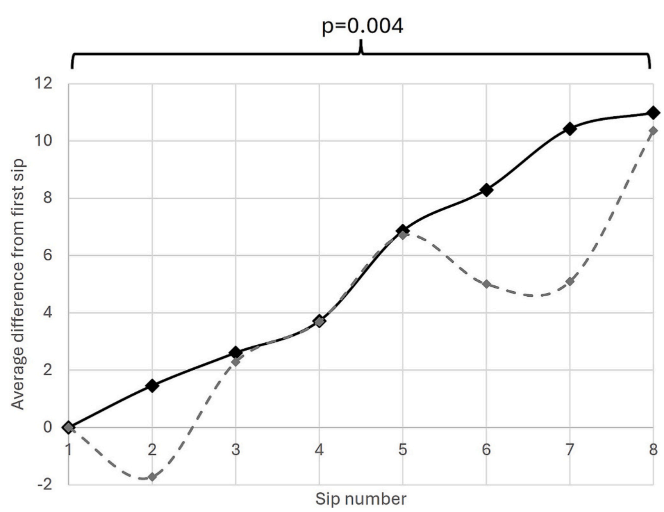

Fig. 5. Average difference in perception score from first sip of mouthdrying over time during the sequential profiling of 10 % w/v whey protein isolate (WPI) suspensions using a blinded (black diamonds, solid line) and unblinded (grey diamonds, dashed line) protocol.

Table 4
Significance (*p*-values) from the analysis of variance model to evaluate panel performance for the assessment of 10 % whey protein isolate through sequential profiling of 8 consecutive sips.

Effect	Attribute			
	Sweetness	Mouthdrying	Salivating	Mouthcoating
Panellist	<0.0001	<0.0001	<0.0001	<0.0001
Sip	0.78	<0.0001	0.40	0.0026
Panellist*Sip	0.18	0.97	0.048	0.40

Ethical Declarations

Ethical review and approval were not necessary for this study as it involved tasting standard commercial practices by a trained sensory panel ($n = 12$; including 1 male and 11 females, aged 35–65 years old) that are employees and have consented to taste and rate food as part of their job. Ethical approval and separate consent are only required from the trained panel where they are tasting non-standard, non-commercial or novel food ingredients. The trained panel work within the ethical and professional practices set out by the IFST: https://www.ifst.org/membership/networksand-communities/special- interest-groups/sensory-science-group/ifst-guidelines.

Financial Declaration

This work was funded through the UKRI BBSRC FoodBioSystems doctoral training partnership (DTP), grant reference BB/T008776/1; as an industrial Case studentship. The industry partner providing part funding was Volac Whey Nutrition Ltd., a manufacturer of whey protein ingredients with a commercial interest in increasing whey protein consumption. Volac Whey Nutrition Ltd. were not involved in the evaluation or interpretation of results to ensure impartiality and took a supervisory reviewing role.

CRediT authorship contribution statement

Holly Giles: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Stephanie P. Bull:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Stella Lignou:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Joe Gallagher:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Marianthi Faka:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Lisa Methven:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

MMR Research Sensory Science Centre in the UK are thanked for their access to the trained sensory panel. Compusense are thanked for their access to their software through the academic consortium.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2025.105628.

Data availability

Data will be made available on request.

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