Influence of Sucrose Levels and Encapsulated Extracts on Sensory Perception: Bitterness Masking and Turmeric Flavor Balance in Functional Instant Drinks

by Singh, K., Low, J., Chaisan, W., Pakakaew, P., Brennan, C.S., Adhikari, B., Newman, L., Posri, W. and Utama-ang, N.

DOI link to the version of record on the publisher's site

Singh, K., Low, J., Chaisan, W., Pakakaew, P., Brennan, C.S., Adhikari, B., Newman, L., Posri, W. and Utama-ang, N. (2025) 'Influence of Sucrose Levels and Encapsulated Extracts on Sensory Perception: Bitterness Masking and Turmeric Flavor Balance in Functional Instant Drinks', *Measurement: Food,* 20, article 100264.

Measurement: Food 20 (2025) 100264

Contents lists available at ScienceDirect

Measurement: Food

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

Influence of Sucrose Levels and Encapsulated Extracts on Sensory Perception: Bitterness Masking and Turmeric Flavor Balance in Functional Instant Drinks

Kanjana Singh [a,b,c,g], Julia Low [c], Worrapob Chaisan [d], Peeraporn Pakakaew [d], Charles Stephen Brennan [c], Benu Adhikari [c], Lisa Newman [c], Wilatsana Posri [f,g], Niramon Utama-ang [a,c,e,g,*]

[a] *Division of Product Development Technology, Faculty of Agro-Industry, Chiang Mai University, Chiang Mai 50100, Thailand*
[b] *Office of Research Administration, Chiang Mai University, Chiang Mai 50100, Thailand*
[c] *School of Science, RMIT University, Melbourne VIC, 3083, Australia*
[d] *Division of Food Science and Technology, Faculty of Agro-Industry, Chiang Mai University, Chiang Mai 50100, Thailand*
[e] *Cluster of high-value products from Thai rice and plants for health, Faculty of Agro-Industry, Chiang Mai University, Chiang Mai 50100, Thailand*
[f] *Department of Food, Land and Agri-Business Management, Harper Adams University, Newport, UK*
[g] *ThaiBrit FoodBridge. Collaboration between Thailand and UK Sensory and Consumer Science Networks for Sustainable Agri-Food Supply, Faculty of Agro-Industry, Chiang Mai University, Thailand*

A R T I C L E I N F O

Keywords:
Masking
Bitterness
Turmeric flavor
Instant drink
Generic descriptive analysis

A B S T R A C T

Taste is crucial for food acceptance, with sweetness generally preferred and bitterness often rejected. Encapsulated green tea and turmeric extracts (COE) previously retained undesirable turmeric aroma, flavor, and bitterness, reducing consumer acceptance. This study evaluated the effect of sucrose (5–15%) in masking these attributes in COE-enriched instant peach drinks. Sensory tests included Generic Descriptive Analysis (GDA) with 13 trained panelists and consumer acceptance testing with 50 Thai consumers. A factorial experiment assessed drinks containing COE (1.0–2.0%), sucrose (5–15%), and peach freeze-dry powder (8%) in 100 mL water. Sucrose levels significantly influenced the physicochemical and sensory properties ($p < 0.05$). Increasing sucrose improved pH, TSS, and liking scores (e.g., turmeric aroma, flavor, sweetness, bitterness, astringency, overall liking), while decreasing color and GDA-rated turmeric attributes. Higher COE levels increased catechin and curcuminoid content but intensified bitterness and reduced flavor acceptance. Turmeric flavor liking was significantly lower at 2.0% COE than at 1.0% and 1.5%. Principal component analysis (79.59% variance explained) identified 15% sucrose and 1.5% COE as the optimal formulation (overall liking: 7.6 ± 1.0). These findings underscore the importance of cross-modal interactions in sensory modulation and offer a sustainable formulation strategy for functional beverages targeting both health benefits and consumer preference.

1. Introduction

Taste is a fundamental driver of food preferences, with sweetness generally associated with liking and bitterness often leading to rejection [24]. From an evolutionary perspective, humans have an innate preference for sweetness, which signals energy-rich and safe food sources, whereas bitterness is often linked to toxins and consequently aversion [8]. Bitterness is also connected to the emotion of disgust, creating a critical challenge for food manufacturers when incorporating health-promoting but bitter-tasting compounds [39]. In recent years, rising health consciousness has fueled consumer demand for functional beverages enriched with bioactive compounds that provide benefits beyond basic nutrition [12,32]. However, these compounds particularly polyphenols such as catechins from green tea and curcuminoids from turmeric often impart undesirable sensory attributes, including bitterness, astringency, and pungency, which can compromise consumer acceptance [6,28,42].

Beyond their sensory drawbacks, these botanical bioactive are essential due to their well-documented health effects. Green tea catechins, especially epigallocatechin gallate (EGCG), have been shown to

* Corresponding author.
E-mail address: niramon.u@cmu.ac.th (N. Utama-ang).

https://doi.org/10.1016/j.meafoo.2025.100264
Received 8 May 2025; Received in revised form 21 October 2025; Accepted 6 November 2025
Available online 8 November 2025

lower LDL cholesterol, reduce oxidative stress, and improve vascular function at daily intakes of approximately 300–800 mg in human trials [19,21,31,47]. Curcuminoids from turmeric exhibit potent antioxidant, anti-inflammatory, and anticancer properties, with effective doses typically ranging from 500 to 1000 mg/day [19,21]. These findings emphasize the functional value of catechins and curcuminoids but also highlight the trade-off between achieving efficacious intake levels and maintaining sensory appeal. Although turmeric is widely used in Thai cuisine, its acceptance in beverages may be more limited due to different sensory expectations and consumption contexts. Cultural familiarity does not automatically extend to all food formats, emphasizing the need to test formulations specifically in the intended product type and target market [30,49].

Taste-masking and flavor modulation strategies have therefore received considerable attention. Sweetness, particularly from sucrose, not only enhances palatability but also suppresses bitterness through mixture suppression mechanisms [9,17]. Sweetness can additionally enhance fruity and floral aromas, improving overall flavor balance [45, 46]. Encapsulation techniques partially mitigate bitterness and pungency [7], but residual sensory attributes often persist. For example, Zokti et al [49] reported that American consumers frequently rejected green tea due to its catechin-related astringency, while Laokuldilok et al [28] showed that turmeric's strong pungency limited its use in certain beverage formulations, even among Thai panelists. Moreover, cross-cultural studies have demonstrated different tolerance levels for bitterness in green tea, with Korean consumers favoring stronger green notes compared to U.S. consumers who prefer milder flavors [30]. These findings underscore the importance of testing specific formulations in the intended product context and target market.

Despite advances in taste-masking strategies, limited research has examined their combined effectiveness in functional beverages containing both green tea and turmeric, particularly in Southeast Asian markets. Sweet bitter interactions remain central to this challenge: binary mixtures of sweet solutions not only enhance perceived sweetness but also reduce bitterness perception, thereby improving overall acceptability [9,40]. Similarly, cross-modal interactions between sweetness and aroma compounds have been shown to intensify fruity notes while suppressing undesirable grassy or pungent attributes [10, 48]. Thus, optimizing sucrose use alongside encapsulation represents a promising approach to balance bioactivity and sensory quality in functional drinks.

The present study investigates how varying sucrose levels (5–15%) and COE concentrations (1.0–2.0%) influence sensory perception, acceptability, and key physicochemical properties (color, pH, total soluble solids, and moisture content) in COE-enriched instant peach drinks. Peach-flavored tea was selected as the model due to its high likability among Thai consumers [42]. Evaluating sweetness perception through sucrose provides a fundamental first step in understanding how it interacts with bitter-tasting compounds, which often retain residual bitterness and astringency despite encapsulation efforts. This study serves as a model to explore these interactions, laying the groundwork for future research on reducing sucrose content. With this foundational knowledge, future studies can investigate alternative approaches, such as leveraging equal-sweetness interactions, to maintain taste balance while lowering sucrose levels. Residual bitterness and astringency remain a key challenge in developing consumer-acceptable functional beverages. This study investigates the effect of varying sucrose levels on the masking of bitterness and turmeric flavor in different concentrations of encapsulated green tea and turmeric extracts, which are used as functional ingredients in instant peach drinks. To address this, the study analyzed the main effect of sucrose levels and encapsulated extracts using analytical and sensory methods. Generic Descriptive Analysis (GDA) and consumer testing evaluated sensory attribute responses and consumer acceptance. Additionally, principal component analysis was applied to categorize sensory variables and identify the optimal formulation that balances sensory appeal and functional benefits, ensuring consumer acceptance while maintaining the integrity of bioactive compounds.

2. Materials and Methods

2.1. Materials and Chemicals

Freeze-dried peach powder was purchased from Fruity Crush Super Food Freeze Dry (Thailand). Granulated sucrose was obtained from Mitr Phol Sugar Corp. (Thailand). Food-grade 95% ethanol was sourced from the Liquor Distillery Organization (Thailand). Pectin, maltodextrin, and inulin were obtained from local suppliers in Thailand (Union Science Co., Ltd, Chiang Mai, Thailand). Green tea leaves (*Camellia sinensis*) and turmeric rhizomes (*Curcuma longa*) were purchased from Raming Tea Co., Ltd. Catechin standards including catechin (C), epigallocatechin gallate (EGCG), epigallocatechin (EGC), epicatechin gallate (ECG), and epicatechin (EC), as well as curcuminoid standards (curcumin (CUR), demethoxycurcumin (DMC), bisdemethoxycurcumin (BDMC)) were obtained from Sigma-Aldrich (USA). Additional chemicals, including phosphoric acid, acetonitrile, tetrahydrofuran, and acetic acid, were sourced from RCI Labscan Co. (Thailand).

2.2. Preparation of Encapsulated Combination Extracts (COE)

Pectin (2.08 g), maltodextrin (15.58 g), and inulin (15.58 g) were dissolved in distilled water and homogenized (5,000 rpm, IKA, Korea). After resting overnight, green tea extract (2 g) and turmeric extract (1 g) in ethanol (5 mL) were added and emulsified (10,000 rpm, cold-water bath). The mixture was frozen (-30°C), freeze-dried (-30°C to 25°C, 48 h, Labconco, USA), ground into powder, and stored (-20°C) until use. The detailed composition and bioactive profile of the COE are provided in Supplementary Table S1.

2.3. Preparation of Instant Peach Drink

A peach concentration of 8% (w/v in 100 mL) was used in the base formulation based on pilot testing, which showed that 50% of participants selected this formulation as the most acceptable, with the highest overall liking score of 8.2 ± 0.7 on a 9-point hedonic scale. In contrast, higher peach levels (10–14%) were consistently rejected due to excessive viscosity, confirming 8% as the optimal base concentration for subsequent factorial testing with COE and varying sucrose levels. The selected COE concentrations provided approximately 15–37 mg/g catechins and 8–19 mg/g curcuminoids, aligning with ranges associated with antioxidant functionality in similar turmeric-green tea systems, while maintaining curcuminoid contents below the FDA GRAS [20] maximum of 20 mg per serving for use as flavoring agents (FDA GRN No. 460) and within the JECFA ADI [2] of 0–3 mg/kg bw/day, ensuring both functional and regulatory safety. The sucrose concentrations were chosen to span a reduced-sucrose level (5%) through the typical range found in Thai beverages (8–12%) to a higher level (15%), allowing for an investigation of the effects of sweetness on bitterness masking and overall sensory acceptance. The choice of 15% as the highest sucrose concentration in the factorial design was guided by the pilot results, which showed that while the formulation with 8% peach and 10% sucrose was the most widely accepted (selected by 50% of participants with an overall liking of 8.2 ± 0.7), the inclusion of 15% sucrose allowed exploration of whether higher sweetness could further improve bitterness masking and acceptance when combined with increased COE levels. The 15% sucrose level, while above typical commercial formulations (8–12% in Thai beverages), was included in this study to establish an upper boundary for evaluating sensory suppression of bitterness. It remains within regulatory limits for ready-to-drink beverages in Thailand (maximum total sugar content of 6–8 g/100 mL) and was used solely for research purposes. Future reformulations may consider reducing sugar using sweetener blends or sensory modulation strategies to align with health guidelines.

2.4. Physiochemical analysis

2.4.1. Color measurement

Color measurements for instant peach powder and instant peach drink with combination extracts were determined using a HunterLab colorimeter (Color Global, MiniScan EZ, USA)

2.4.2. Moisture content determination

The moisture content of an instant peach drink with combination extracts powder was determined using the AOAC method [1]. Two grams of sample were weighed and dried in an oven at 105°C until a constant weight was obtained. The moisture content was calculated by the following equation: (1)

$$Moisture\ content\ (\%) = (W1 - W2)/W1 \times 100 \quad (1)$$

Where W1 is the sample weight before drying and W2 is the sample weight after drying

2.4.3. **Water activity determination (aw)**

The water activity of samples was determined using Aqualab TE3 (Decagon Device, Inc., USA).

2.4.4. Total soluble solid (Bx°) determination

The total soluble solid of instant peach drink samples was determined using a hand refractometer (0% - 45% bx°). The total soluble solid of the sample was reported as °Bx using a handheld refractometer (Atago PAL-1, Atago Co. Ltd., Tokyo, Japan).

2.4. 5 pH determination

The pH was determined using a digital pH meter according to AOAC 981.12 (2000) method.

2.4.6. Catechin and curcuminoid content determination

Five catechin standards catechin (C), epigallocatechin gallate (EGCG), epigallocatechin (EGC), epicatechin gallate (ECG), and epicatechin (EC) were employed to determine catechin levels. Stock solutions of each catechin at 1.0 mg/mL in 60% ethanol were prepared and stored at -20°C until use. Mixed catechin standards were then prepared by diluting the stock solution to 0.05, 0.025, 0.0125, and 0.00625 mg/mL in 60% ethanol. A curcuminoid standard, comprising curcumin (CUR) (80%), demethoxycurcumin (DMC) (17%) and bisdemethoxycurcumin (BDMC) (3%), was also prepared and stored at -20°C. Curcuminoid standards were diluted to 0.05, 0.025, 0.0125, and 0.00625 mg/mL in 95% ethanol. Measurement analysis was conducted using an Agilent 1200 series (Agilent Technologies, Santa Clara, CA, USA) HPLC system with a C18 column (4.6 × 250 mm, Waters, Ireland), following (Singh et al., 2022; Singh et al., 2022)

2.5. Sensory Evaluation

2.5.1. Product formulation and pilot testing

As mentioned in Section 2.3, a preliminary pilot study was conducted to determine the optimal base formulation of the instant peach drink before incorporating COE. Ten sample formulations were prepared by varying the concentrations of freeze-dried peach powder (6–14%) and sucrose (5–15%) in 100 mL of water. Twenty participants (aged 25–50 years), screened using the same criteria as in the main study, evaluated these samples in a controlled 25 °C laboratory environment. Participants rated appearance, aroma, flavor, taste, viscosity, overall liking, and aftertaste using a 9-point hedonic scale. Each sample (50 mL) was coded with three-digit numbers and presented sequentially, with palate cleansing using water and plain crackers between samples. Results indicated that 50% of participants selected the formulation containing 8% peach powder and 10% sucrose as the most acceptable, which also achieved the highest mean overall liking score of 8.2 ± 0.7. Based on these outcomes, 8% peach was fixed as the base concentration, with sucrose levels up to 15% included in the subsequent factorial design to explore their effects on bitterness masking and sensory acceptance when combined with COE. The outcomes of this preliminary pilot test were used solely to determine the base formulation and are not presented in the results section.

2.5.2. Generic Descriptive Analysis (GDA)

Participants aged 18–50 years were selected based on criteria including non-smoking status, non-pregnancy, no medication use or food allergies, and the ability to accurately communicate observations and use 150-mm unstructured scales, with less than 10% variation in solution tests. An initial screening of 18 participants was conducted, from which 13 qualified judges were selected based on their sensory differentiation and consistency performance. Panelists were also screened for their ability to discriminate basic tastes relevant to this study, using simple solution tests with sucrose (2 g/100 mL vs. water) for sweetness, caffeine (0.1 g/100 mL vs. water) for bitterness, and a triangle test to ensure reliable differentiation. Only those who demonstrated correct identification and maintained variation below 10% across replicates were included [33]. Thirteen judges developed sensory attributes in two 90-minute sessions: one for green tea and one for turmeric, covering appearance, aroma, flavor, taste, and aftertaste. The developed sensory attributes, their definitions, and the reference standards used during training are provided in Supplementary Table S2-S6. Two 60-minute familiarization sessions were conducted to standardize sensory interpretation. Nine training sessions (each lasting approximately 90 minutes) in total were conducted to reinforce attribute definitions and reference materials. Judges rated samples on a 150-mm scale, ensuring standard deviations under 10% in preliminary tests [37]. After training, the basic formula of an instant peach drink combined with COE was evaluated by 13 participants to select sensory terms present in the product. This selection was based on sensory attributes referenced from a previous study's sensory attributes analysis conducted on COE [41]. After that, samples were tested individually in random order within each of the three replications using the 0–150 mm scale in a controlled laboratory environment with a temperature set at 25°C. The samples in plastic cups (50 mL/sample) were presented sequentially and coded with unique three-digit random numbers before being served to the panelists. Water and plain crackers were provided to cleanse the palate between samples. Panelists were also instructed to wait approximately 2 minutes between tastings to minimize potential carry-over effects, particularly for bitterness [26].

2.5.3. Consumer Acceptance

For the main consumer acceptance test, fifty participants (20–50 years) evaluated nine formulations of instant peach drinks prepared by factorial combinations of sucrose (5%, 10%, 15%) and COE (1.0%, 1.5%, 2.0%) using the base product established in the pilot study (8 g peach powder in 100 mL water). Participants from Chiang Mai University, Thailand, were recruited based on inclusion criteria, and the samples were presented using a balanced incomplete block design (BIBD). Participants rated appearance, aroma, flavor, taste, overall liking, and aftertaste on a 9-point hedonic scale in a controlled 25 °C laboratory setting. Each sample (50 mL) was coded with three-digit numbers and presented sequentially, with palate cleansing using water and plain crackers between samples. Panelists were also instructed to wait approximately 2 minutes between tastings to minimize potential carry-over effects, particularly for bitterness.

2.6. Statistical Analysis

All physicochemical analyses were conducted in triplicate (N = 3), with data expressed as the mean ± standard deviation. For the sensory evaluation, the generic descriptive analysis (GDA) was based on ratings from 13 trained panelists (N = 13), while the consumer acceptance test involved 50 consumers (N = 50). A two-way factorial analysis of variance (ANOVA) was performed to evaluate the effects of sucrose levels and COE levels, as well as their interaction, on sensory and consumer acceptance responses. Both sucrose (%) and COE (%) levels were treated as continuous variables in the two-way factorial ANOVA to evaluate their main and interaction effects on each response variable. Interaction terms (sucrose × COE) were formally tested and reported for each variable. Where significant ($p < 0.05$), interaction results were interpreted accordingly. Post-hoc comparisons among means were conducted using Duncan's multiple range test (DMRT) to identify statistically significant differences, with significance set at $p < 0.05$. In addition, a principal component analysis (PCA) biplot was performed on mean-centered sensory (GDA intensities), consumer acceptance, and physicochemical data to integrate these datasets. This approach projects product formulations and consumer preference vectors into a common multivariate space, thereby providing a visual representation of how product attributes, hedonic responses, and compositional factors are interrelated. All statistical analyses were performed using IBM SPSS Statistics, version 26 (IBM Corp., Armonk, NY, USA).

2.7. Human Research Ethics

The study was conducted following the Declaration of Helsinki and was approved by the Chiang Mai University Research Ethics Committee (CMUREC No.63/157). Informed consent was obtained from all participants.

3. Results and Discussion

This study aimed to optimize the formulation of an instant peach drink containing encapsulated green tea and turmeric extracts (COE) by evaluating how sucrose levels (5–15%) interact with COE (1.0–2.0%) in modifying sensory perception and masking undesirable flavors. A pilot study with 20 participants evaluated formulations containing peach freeze-dried powder (6–14%) and sucrose (5–15%) in 100 mL of water. Among these, the formulation with 8% peach powder and 10% sucrose was selected as the most acceptable by 50% of participants, achieving the highest mean overall liking score of 8.2 ± 0.7 on a 9-point hedonic scale. Although lower acceptance was observed for formulations with higher sucrose levels, 15% sucrose was included in subsequent factorial testing to explore its potential for enhancing bitterness masking when combined with increased COE levels. Based on these pilot findings, the formulation with 8% peach powder was fixed as the base, and sucrose concentrations ranging up to 15% were further investigated in combination with COE additions.

3.1. Effects of Sucrose and COE on Physicochemical Properties

Moisture content ranged from 2.26% to 3.28% (Table 1), aligning with Thai FDA standards (<8%) for dried beverages, while water activity (aw) remained stable (0.3539–0.3607, $p>.05$), indicating no significant impact of sucrose or COE levels on product stability. Color analysis (L a b*) showed that L* (lightness) ranged from 81.84 to 86.04, influenced by sucrose and freeze-dried peach powder, while redness (a*) varied from 0.70 to 1.60, and yellowness (b*) from 27.10 to 40.24, attributed to COE (Table 1). Higher sucrose levels decreased a* and b* ($p<.05$), lightening the powder due to sucrose dilution, whereas increased COE levels reduced L* while increasing a* and b*, intensifying redness and yellowness from COE pigments. Significant interaction effects (sucrose × COE) were also observed for L*, a*, and b* values in the powder samples ($p = 0.001$ for all), indicating that the influence of COE on color expression was modulated by sucrose level. For instance, b* values increased sharply only at higher COE concentrations when combined with low sucrose, whereas this effect was less pronounced at high sucrose. In instant peach drink solutions, L* (28.91–38.12), a* (-2.15 to -2.97), and b* (14.55–20.50) were significantly influenced by sucrose and COE levels ($p<.05$) (Table 2), with increased solubility of peach powder, driven by sucrose and COE, reducing lightness while enhancing redness, likely due to turmeric pigments. Significant interaction effects were detected for these color parameters in solution ($p = 0.001$), reinforcing that the extent of color intensification depended on the combined levels of both sucrose and COE. Sucrose may influence the optical properties of the beverage matrix, thereby modifying how COE pigments like curcuminoids are expressed in solution [4]. Total soluble solids (TSS) increased significantly with higher sucrose and COE levels, due to greater solubility (Tables 1), consistent with Alharaty and Ramaswamy [3], who reported increased TSS and reduced acidity with increasing sucrose content. Similarly, Samborska et al [38] found that adding berry juice to a sugar solution increased solubility, enhancing color intensity and reducing lightness. The pH (5.27–5.75) also increased with sucrose addition ($p<.05$) but remained unaffected by COE levels (Tables 1 and 3), as sucrose acts as a pH-neutral component. Interaction effects for pH were non-significant ($p = 0.550$), indicating that changes in pH were primarily driven by sucrose alone. For pH, only the main effect of sucrose (%) was significant ($p = 0.001$), while no interaction effect (sucrose × COE) was observed ($p = 0.550$). Pairwise comparisons showed that all sucrose levels (5%, 10%, and 15%) differed significantly, with mean pH values of 5.33 ± 0.06, 5.55 ± 0.04, and 5.69 ± 0.02, respectively. This result aligns with previous findings that sucrose, being a non-ionic solute, does not contribute to acidity or proton exchange in solution [48]. Catechin and curcuminoid content ranged from 15.164 to 37.158 mg/g and 8.272 to 18.810 mg/g, respectively, with COE levels significantly influencing both ($p<.05$), whereas sucrose had no significant impact (Tables 2). Nonetheless, interaction effects

Table 1
Moisture content, total soluble solid of instant peach drink and L*, a*, b* of instant peach drink powder and instant peach drink obtained by different sucrose levels and encapsulated combination extracts (COE)[1].

Sucrose (%)	COE (%)	MC (%) (ns)	TSS (Brix°)	pH (ns)	L* powder (ns)	a* Powder	b* Powder
5.0	1.0	3.28±0.03	5.7±0.1^{g}	5.33±0.06	84.58±1.48	0.70±0.07^{d}	27.10±0.39^{f}
5.0	1.5	3.24±0.06	6.1±0.1^{f}	5.27±0.05	83.41±1.09	0.84±0.04^{c}	37.13±0.18^{c}
5.0	2.0	3.26±0.03	6.3±0.1^{e}	5.29±0.05	81.84±0.23	1.60±0.05^{a}	40.84±0.17^{a}
10.0	1.0	2.57±0.04	8.0±0.1^{e}	5.55±0.04	85.14±0.06	0.65±0.03^{de}	27.35±0.76^{f}
10.0	1.5	2.65±0.03	8.1±0.1^{e}	5.57±0.04	83.78±0.64	0.83±0.02^{c}	32.55±0.64^{d}
10.0	2.0	2.59±0.06	8.4±0.1^{d}	5.54±0.02	82.10±0.30	1.42±0.02^{b}	40.24±1.03^{ab}
15.0	1.0	2.33±0.05	10.1±0.1^{c}	5.69±0.02	86.04±0.56	0.61±0.02^{e}	27.17±0.93^{f}
15.0	1.5	2.27±0.06	10.5±0.2^{b}	5.75±0.06	84.03±0.14	0.80±0.03^{c}	31.10±0.86^{e}
15.0	2.0	2.26±0.04	10.8±0.1^{a}	5.74±0.05	82.58±0.43	1.37±0.04^{b}	39.51±0.38^{b}
Interaction P-*values*		0.001	0.001	0.550	0.001	0.001	0.001

[1] Values are the mean ± standard deviation (n = 3); ns: not significant ($p>.05$) within the same column
[a-e]represents the significant difference in the columns as $p<.05$ by Duncan's multiple range test (DMRT).
ns: not significant ($p>.05$) within the same column
P-*values* in the final row represent the interaction effects (sucrose × COE) as tested in the factorial ANOVA.

Table 2
L*, a*, b*, catechin content and curcuminoid content of instant peach drink obtained by different sucrose levels and encapsulated combination extracts (COE)[1].

Sucrose (%)	COE (%)	L*Drink (ns)	a*Drink (ns)	b*Drink	Catechin content (mg/g)	Curcuminoid Content (mg/g)
5.0	1.0	28.91±0.23	-2.97±0.04	14.55±0.43^{e}	16.640±1.325^{d}	8.657±1.605^{d}
5.0	1.5	29.16±0.46	-2.72±0.06	15.57±0.37^{d}	24.508±2.245^{c}	12.616±0.998^{c}
5.0	2.0	30.23±0.46	-2.68±0.20	16.11±0.22^{d}	35.149±2.817^{a}	16.933±1.241^{ab}
10.0	1.0	29.80±0.29	-2.79±0.01	16.05±0.83^{d}	15.164±1.120^{d}	8.272±1.656^{d}
10.0	1.5	30.60±0.12	-2.41±0.04	17.55±0.27^{c}	28.190±2.103^{b}	12.567±1.051^{c}
10.0	2.0	31.76±0.31	-2.24±0.16	19.49±0.90^{b}	37.158±1.670^{a}	18.681±1.399^{a}
15.0	1.0	35.28±0.11	-2.77±0.16	17.51±0.28^{c}	16.341±1.369^{d}	8.933±0.681^{d}
15.0	1.5	36.11±0.51	-2.35±0.14	19.69±0.39^{ab}	24.903±1.723^{bc}	16.333±1.331^{b}
15.0	2.0	38.12±0.73	-2.15±0.04	20.50±0.26^{a}	35.304±2.586^{a}	18.810±1.881^{a}
Interaction P-*values*		0.001	0.001	0.001	0.001	0.001

[1] Values are the mean ± standard deviation (n = 3); ns: not significant (p>.05) within the same column
$^{a-e}$represents the significant difference in the columns as *p*<.05 by Duncan's multiple range test (DMRT).
ns: not significant (*p*>.05) within the same column
P-*values* in the final row represent the interaction effects (sucrose × COE) as tested in the factorial ANOVA.

Table 3
Generic descriptive analysis intensity of sensory attributes of instant peach powder and instant peach drink obtained by different levels of sucrose and encapsulated combination extracts (COE)[1].

Sucrose (%)	COE (%)	Turmeric aroma (powder) (mm)	Green tea aroma (powder) (mm)	Turmeric aroma (mm)	Green tea aroma (mm) (ns)	Turmeric flavor (mm)	Green tea flavor (mm) (ns)	Sweet taste (mm)	Bitterness (mm)	Sweet aftertaste (mm) (ns)	Turmeric aftertaste (mm)
5.0	1.0	1.0 ±0.0^{f}	1.0±0.0^{f}	1.0±0.0^{f}	1.0±0.0	1.0±0.0^{g}	1.0±0.0	15.0 ±0.0^{f}	2.1±0.0^{e}	1.0±0.0	1.0±0.0^{d}
5.0	1.5	15.8±0.0^{c}	2.5±0.1^{d}	5.2±0.1^{d}	1.0±0.0	12.3±0.1^{d}	1.0±0.0	14.8 ±0.0^{f}	3.8±0.0^{c}	1.0±0.0	1.0±0.0^{d}
5.0	2.0	22.4±0.0^{a}	6.2±0.6^{a}	27.2±0.1^{a}	1.7±0.0	23.7±0.1^{a}	1.0±0.0	14.6 ±0.1^{f}	7.7±0.0^{a}	1.0±0.0	11.6±0.2^{a}
10.0	1.0	1.0±0.0^{f}	1.0±0.0^{f}	1.0±0.0^{f}	1.0±0.0	1.0±0.0^{g}	1.0±0.0	31.8 ±0.1^{d}	1.6±0.0^{f}	1.0±0.0	1.0±0.0^{d}
10.0	1.5	14.7±0.0^{d}	2.0±0.0^{e}	5.2±0.0^{d}	1.0±0.0	8.6±0.1^{e}	1.0±0.0	31.5 ±0.1^{d}	3.1±0.0^{d}	1.0±0.0	1.0±0.0^{d}
10.0	2.0	17.8±0.0^{b}	5.3±0.1^{b}	17.4±0.1^{b}	1.7±0.0	21.7±0.1^{b}	1.0±0.0	29.6 ±0.1^{e}	4.6±0.0^{b}	1.0±0.0	7.5±0.2^{b}
15.0	1.0	1.0±0.0^{f}	1.0±0.0^{f}	1.0±0.0^{f}	1.0±0.0	1.0±0.0^{g}	1.0±0.0	58.4 ±0.1^{a}	1.1±0.0^{g}	1.7±0.0	1.0±0.0^{e}
15.0	1.5	12.9±0.0^{e}	1.8±0.0^{e}	3.6±0.0^{e}	1.0±0.0	6.9±0.0^{f}	1.0±0.0	57.4 ±0.1^{b}	2.7±0.0^{e}	1.7±0.0	6.0±0.5^{c}
15.0	2.0	17.4±0.0^{b}	4.9±0.1^{c}	13.1±0.1^{c}	1.7±0.0	16.3±0.1^{c}	1.0±0.0	56.8 ±0.1^{c}	2.1±0.0^{e}	1.6±0.0	6.0±0.7^{c}
Interaction P-*values*		0.001	0.001	0.001	0.001	0.001	0.431	0.001	0.001	0.001	0.001

[1] Values are the mean ± standard deviation (n = 13); ns: not significant (p>.05) within the same column; $^{a–f}$ represents the significant difference in the columns as *p*<.05 by Duncan's multiple range test (DMRT); ns: not significant (*p*>.05) within the same column; P-*values* in the final row represent the interaction effects (sucrose × COE) as tested in the factorial ANOVA

were significant for both catechin and curcuminoid content (p = 0.001). Catechin and curcuminoid levels increased markedly with higher COE concentrations, particularly at moderate to high sucrose levels (10–15%), indicating that sucrose concentration influenced the extractability and retention of these bioactive during formulation.

3.2. *Effects of Sucrose and COE on Sensory Attribute Intensities (GDA Analysis)*

Trained panelists evaluated how varying sucrose and COE levels influenced the perception of bitterness, pungency, sweetness, and other key sensory attributes in the instant peach drink using generic descriptive analysis (GDA). Ten attributes were identified and rated to capture these effects (Table 3). Overall, the addition of sucrose significantly increased sweetness intensity and reduced bitterness, while higher COE levels enhanced the aroma and flavor attributes of turmeric and green tea. Significant sucrose × COE interaction effects were also observed, reflecting the combined influence of sweetness and functional ingredient levels on the sensory profile.

3.2.1. *Impact of Sucrose and COE on Aroma Perception*

The results indicate that sucrose and COE concentrations individually influenced aroma perception. Notably, the main effect indicated that an increased sucrose level (from 5% to 15%) in instant drink powder significantly decreased the intensity of green tea and turmeric aromas, while an increase in COE increased both green tea and turmeric aromas (Table 3). For example, at 5% sucrose with 1.0% COE, the intensity of turmeric and green tea aromas was minimal (1.0 ± 0.0 mm). However, at 5% sucrose with 2.0% COE, the intensities rose sharply to 27.2 ± 0.1 mm and 6.2 ± 0.6 mm, respectively. Conversely, increasing sucrose at a fixed COE level suppressed these attributes; for instance, turmeric aroma declined from 27.2 mm at 5% sucrose to 13.1 mm at 15% sucrose (−52%). Similar reductions were observed for green tea aroma. Importantly, significant sucrose × COE interactions were found for nearly all sensory attributes ($p < 0.05$), except green tea flavor ($p = 0.431$). These interactions indicate that the extent of sucrose masking varied with the concentration of COE, as both factors were systematically varied in the factorial design. For example, bitterness and turmeric aftertaste were highest at 5% sucrose with 2.0% COE (7.7 ± 0.0 mm and 11.6 ± 0.2 mm, respectively), but were substantially suppressed at 15%

sucrose with the same COE concentration (2.1 ± 0.0 mm and 6.0 ± 0.7 mm). In contrast, sweetness increased disproportionately with sucrose concentration, rising from 15.0 mm at 5% sucrose to 58.4 mm at 15% sucrose, while still interacting with COE to modulate the perception of bitterness and aroma. The reduction in turmeric and green tea aroma perception with higher sucrose is explained by two complementary mechanisms: (i) cross-modal suppression, where increased sweetness intensity perceptually suppresses bitterness- and pungency-linked flavor notes, thereby lowering the integrated sensory profile; here, flavor refers to the combined experience of taste, aroma rather than aroma release alone [14,26]; and (ii) physicochemical effects, where higher sucrose levels reduce water activity and increase viscosity, thereby limiting the release and retronasal perception of volatile compounds [18]. Additionally, aroma–aroma interactions may occur, with pungent or earthy notes from turmeric and green tea being masked by sweeter or peach-associated volatiles [11,15,23]. These explanations align with prior work showing that sucrose can decrease the perception of undesirable aromas through both perceptual and matrix-related mechanisms [16]. Together, these findings confirm that sucrose not only increases sweetness but also dynamically interacts with COE to reshape the overall flavor profile of the peach drink. Moreover, the factorial ANOVA revealed statistically significant interaction effects (p = 0.001) between sucrose and COE concentrations for all aroma attributes, including turmeric aroma and green tea aroma in both powder and drink forms (Table 3). These results demonstrate that the perceptual expression of volatile compounds was not solely a function of either sugar or COE levels but was instead contingent on their combination. For example, the turmeric aroma in powder sharply increased with COE at low sucrose (from 1.0 to 27.2 mm between 1% and 2% COE at 5% sucrose), whereas this increase was more muted at high sucrose levels (e.g., from 12.9 to 17.4 mm at 15% sucrose). This interaction pattern suggests that sucrose suppressed aroma release or perception more effectively at higher COE concentrations. Similar trends were observed for green tea aroma, particularly in the drink form, indicating that the masking effects of sucrose are magnified when volatile loads are high potentially due to both perceptual and physicochemical modulation [14,18].

3.2.2. *Impact of Sucrose and COE on Flavor Perception*

The green tea flavor intensity remained largely unchanged across treatments at approximately 1.0 ± 0.01 mm, while turmeric flavor varied markedly from 1.00 ± 0.01 to 23.68 ± 0.09 mm (Table 3). Increasing sucrose levels from 5% to 15% progressively reduced the turmeric flavor intensity, for example, from 23.68 mm to 16.25 mm at a fixed 2.0% COE level (Table 3). Conversely, raising the COE concentration from 1.0% to 2.0% at a constant 5% sucrose level significantly increased the turmeric flavor from 1.72 mm to 23.68 mm, while the green tea flavor remained unaffected. These findings suggest that COE concentration predominantly drives turmeric flavor intensity, whereas higher sucrose levels effectively mask it. The overall trends of sucrose and COE effects on sensory intensities and liking were summarized in Tables 3 and 4, which clearly illustrate the direction of changes for each sensory attribute. This complementary effect between COE and sucrose helps achieve a more balanced flavor profile in the instant peach drink. In addition, significant interaction effects between sucrose and COE (p = 0.001) were observed for turmeric flavor, sweet taste, bitterness, sweet aftertaste, and turmeric aftertaste (Table 4). At low sucrose levels (5%), increasing COE from 1.0% to 2.0% sharply increased turmeric flavor (1.72 to 23.7 mm) and turmeric aftertaste (1.0 to 11.6 mm). However, at high sucrose levels (15%), the same COE increment produced a smaller increase (9.6 to 16.3 mm; 0.6 to 6.0 mm). Conversely, sweet taste perception was maximized under the high-sucrose and high-COE condition (up to 58.4 mm). At the same time, bitterness showed the most significant suppression in the same condition, indicating a context-dependent modulation of sensory perception.

Previous classical studies have shown that sucrose influences flavor perception in various beverages. Stampanoni [43] reported that sucrose addition significantly increased sweetness and intensified the perception of citrus flavors in soft drinks and fruit nectars. Similarly, Pangborn et al [36] demonstrated that sucrose enhanced fruit nectar flavor intensity, reinforcing the role of sweetness in modifying taste perception. While these foundational studies provide key insights, they primarily focus on Western consumer cohorts, particularly American populations. More recent research has expanded this understanding by examining the interaction between sucrose and bitter compounds such as caffeine. For example, Travers et al [44] demonstrated that reducing bitterness in caffeine-containing beverages allowed for a reduction in sucrose concentration while maintaining acceptability. In contrast, the present study extends this understanding by applying these concepts in a

Table 4
Sensory attribute hedonic scores: appearance, color, overall aroma, turmeric aroma, green tea aroma of instant peach drink obtained by different levels of sucrose and encapsulated combination extracts (COE)[1].

Sucrose (%)	COE (%)	Appearance (ns)	Color (ns)	Overall aroma (ns)	Turmeric aroma	Green tea aroma (ns)
5.0	1.0	6.2±0.8	6.3 ±1.3	6.2±1.1	7.5±0.7[a]	7.5±0.7
5.0	1.5	6.0±0.9	6.4 ±1.4	6.5±1.2	7.0±0.7[b]	7.4±0.7
5.0	2.0	6.1±1.1	6.7 ±1.5	6.5±1.1	6.5±0.9[ab]	7.4±0.5
10.0	1.0	6.2±1.1	6.2 ±1.0	6.4±1.1	7.3±0.8[ab]	7.4±0.7
10.0	1.5	6.1±1.1	6.4 ±1.1	6.4±1.3	6.7±0.9[ab]	7.6±0.5
10.0	2.0	6.3±1.1	6.9 ±1.3	6.6±1.0	6.9±1.0[ab]	7.6±0.5
15.0	1.0	6.3±1.3	6.3 ±1.0	6.5±1.2	5.6±0.5[c]	7.7±1.1
15.0	1.5	6.2±1.1	6.2 ±1.1	6.5±1.4	6.6±1.1[b]	7.9±1.2
15.0	2.0	6.2±1.1	7.1 ±1.2	6.7±0.9	7.3±0.6[ab]	7.6±1.7
Interaction P-*values*		0.001	0.001	0.001	0.001	0.001

Sensory attribute hedonic scores: bitter, astringent, overall liking, aftertaste of instant peach drink obtained by different levels of sucrose and encapsulated combination extracts (COE)[1]

Sucrose (%)	COE (%)	Bitter (ns)	Astringent (ns)	Overall liking (ns)	Aftertaste (ns)
5.0	1.0	5.1 ±0.7[c]	6.5±0.9	6.2±0.8[b]	6.9±1.1
5.0	1.5	5.4 ±0.5[c]	6.4±0.9	5.3±0.9[c]	6.5±0.9
5.0	2.0	5.3 ±0.8[c]	5.8±0.8	5.1±0.7[c]	6.3±1.1
10.0	1.0	6.5 ±0.9[ab]	6.9±0.7	8.2±0.6[a]	7.0±1.3
10.0	1.5	6.6 ±0.9[ab]	6.6±1.2	8.0±1.0[a]	7.7±1.0
10.0	2.0	6.8 ±1.0[a]	6.5±1.0	7.7±1.2[a]	7.9±1.0
15.0	1.0	7.2 ±1.2[a]	7.2±0.8	7.5±1.0[a]	7.7±1.1
15.0	1.5	6.8 ±1.3[ab]	7.4±1.0	7.6±1.0[a]	7.8±1.1
15.0	2.0	6.7 ±0.7[ab]	7.5±0.7	7.7±1.1[a]	7.7±1.0
Interaction p-*values*		0.001	0.001	0.001	0.001

[1] Values are the mean ± standard deviation (n = 50); ns: not significant (p>.05) within the same column

[a-e]represents the significant difference in the columns as $p<.05$ by Duncan's multiple range test (DMRT).

ns: not significant ($p>.05$) within the same column

P-*values* in the final row represent the interaction effects (sucrose × COE) as tested in the factorial ANOVA.

different cultural context, specifically among Thai consumers, who may have distinct flavor preferences and sensitivities to bitterness. Although Thai consumers are accustomed to using green tea and turmeric in traditional cuisine, there is limited evidence on their acceptance thresholds for the bitterness intensity in beverages. This highlights the need for further cross-cultural investigations to gain a more precise understanding of regional sensory preferences [30,49]. The findings confirm that sweetness perception plays a crucial role in masking undesirable flavors, such as the bitterness and pungency of turmeric, but also highlight a key challenge maintaining the functional benefits of COE while ensuring consumer acceptability. This study provides a more regionally relevant perspective, demonstrating how sucrose and COE levels each influence sensory perception in this consumer group, thus broadening the application of taste-masking strategies beyond Western populations. The interaction results further emphasize that sucrose not only masks undesirable turmeric bitterness but also attenuates the COE-driven flavor enhancement, while simultaneously amplifying perceived sweetness. Such cross-modal interactions highlight the need for tailored formulation strategies in Thai consumers, balancing functional authenticity with sensory acceptability.

The results of this study demonstrate that increasing sucrose levels in a peach-based instant drink significantly modified flavor perception by reducing the intensity of turmeric flavor and bitterness. At a constant 2% COE level, increasing sucrose from 5% to 15% significantly reduced turmeric flavor intensity (23.68 mm to 16.25 mm) while increasing sweet taste perception (14.57 mm to 56.83 mm) (Table 3).

The reduction in turmeric perception with increasing sucrose levels suggests that sucrose does not merely mask bitterness but also modulates the perception of other sensory attributes, particularly the pungency of turmeric, which is associated with trigeminal activation. This aligns with previous research showing that sweetness can suppress trigeminal sensations. For example, Mennella et al [34] and Keast et al [25] showed that sucrose suppresses the bitterness of compounds such as quinine and caffeine through taste–taste interactions. In addition, sucrose has been found to reduce oral trigeminal sensations, such as capsaicin-induced burning or irritation, further influencing overall flavor perception [17, 29]. Similarly, Nolden et al [35] reported that sweet taste can decrease capsaicin-induced irritation by approximately 50%, highlighting the role of sucrose in modulating trigeminally mediated sensations. These findings also support research on the influence of sucrose on volatile interactions and taste perception mechanisms. Hornung and Enns [22] reported that sucrose enhances fruity flavor perception, while Cliff and Noble [10] found that glucose intensified peach flavor. Similarly, Fan et al [13] showed that certain strawberry volatiles enhance sweetness perception independently of sugar content, suggesting that sucrose influences overall flavor balance beyond simple masking. In this study, sucrose may have reduced the perceived intensity of turmeric-related notes, thereby potentially altering the overall flavor balance. These findings suggest a bidirectional relationship, whereby sucrose dampens COE-driven bitterness and pungency, while COE enhances sweetness perception under high-sucrose conditions [10,13,22]. This supports the notion that the perceptual outcome of functional beverages is shaped by interactive, rather than independent, contributions of sweetness and bioactive flavors.

3.3. Effects of Sucrose and COE on Consumer Acceptance

The results indicated that higher sucrose levels significantly reduced the liking scores of turmeric aroma, turmeric flavor, and overall flavor, despite leading to an overall increase in preference and liking scores (Tables 4). This suggests that while sucrose enhances sweetness and overall acceptability, it suppresses the distinct sensory attributes of turmeric. This effect may be explained by mixture suppression, where the presence of sucrose suppresses the perception of bitterness from curcuminoids through known taste–taste inhibitory mechanisms [5,27, 29]. Additionally, since turmeric also activates trigeminal sensations related to pungency and astringency, increased sweetness might further dampen the overall sensory impact, reducing their contribution to flavor perception. This cross-modal suppression effect is particularly relevant in functional beverages, where the balance between bioactive compounds and consumer palatability has not been extensively studied. Similar effects have also been observed in sugar-sweetened beverages containing caffeine. Keast et al [25] highlighted that caffeine's bitterness increases sugar requirements to maintain palatability, a phenomenon known as the caffeine–calorie effect. In addition, significant interaction effects between sucrose and COE ($p = 0.001$) were observed for several attributes, including appearance, color, overall aroma, turmeric aroma, bitterness, astringency, overall liking, and aftertaste (Table 4). At lower sucrose levels (5%), increasing COE tended to reduce overall liking (from 6.2 to 5.1), despite higher scores for turmeric aroma. In contrast, at moderate sucrose levels (10%), COE contributed positively to visual appeal (appearance and color liking increased from 6.2 to 6.9), while overall liking reached its maximum (8.2) at 10% sucrose combined with 1.0% COE. At high sucrose levels (15%), higher COE reduced the negative impact of turmeric aroma but did not further increase overall liking, suggesting an optimum sucrose COE balance for consumer acceptance.

Beyond its impact on turmeric-related attributes, sucrose levels also influenced overall taste, sweetness, bitterness, astringency, preference, and aftertaste, with higher sucrose concentrations correlating with increased consumer liking scores. These findings align with previous research, which shows that sugar can modify overall flavor perception by enhancing sweetness while simultaneously suppressing bitterness [10,22]. Moreover, sugar can interact with volatiles to modify the perception of sweetness and overall flavor [13]. This suggests that sucrose not only masks bitterness but also contributes to a more balanced flavor profile by enhancing sweet-associated aromas. These interaction patterns indicate that sucrose not only masks bitterness but also moderates the perceptual impact of COE, creating a balance between visual appeal and flavor acceptability. Such bidirectional modulation suggests that consumer liking cannot be explained by sucrose or COE alone but by their combined effects.

COE levels had a distinct effect on consumer acceptance, particularly in relation to color and turmeric flavor (Table 4). Higher COE concentrations resulted in increased liking scores for color, likely due to the rich golden hue provided by curcuminoids, which consumers found visually appealing. However, higher COE levels simultaneously reduced acceptance of the turmeric flavor, suggesting that although consumers appreciated the enhanced visual appeal from increased COE concentration, the accompanying intensification of turmeric flavor exceeded the acceptable threshold, leading to a decrease in overall liking. This may be explained by the interaction between curcuminoids and taste receptors, as curcuminoids have been shown to activate bitter taste receptors and trigeminal pathways, contributing to decreased liking scores at higher COE levels [32]. These findings suggest that while sucrose effectively masks the bitterness and pungency associated with turmeric, it may also reduce the perceptible sensory cues linked to its bioactive components. This underscores the challenge of maintaining both palatability and the distinctive sensory qualities of functional ingredients in product development. The interaction findings further support this interpretation sucrose attenuated the negative sensory impact of higher COE on turmeric flavor and aftertaste, while enhancing acceptance of visual cues.

3.4. Principal Component Analysis

A principal component analysis (PCA) biplot was conducted to integrate GDA intensities, consumer liking scores, and physicochemical parameters across the nine peach drink formulations (Figure 1). This PCA was performed on sample mean data to provide a descriptive multivariate overview of relationships among variables. The first two principal components PC1 and PC2 explained 79.6% of the total

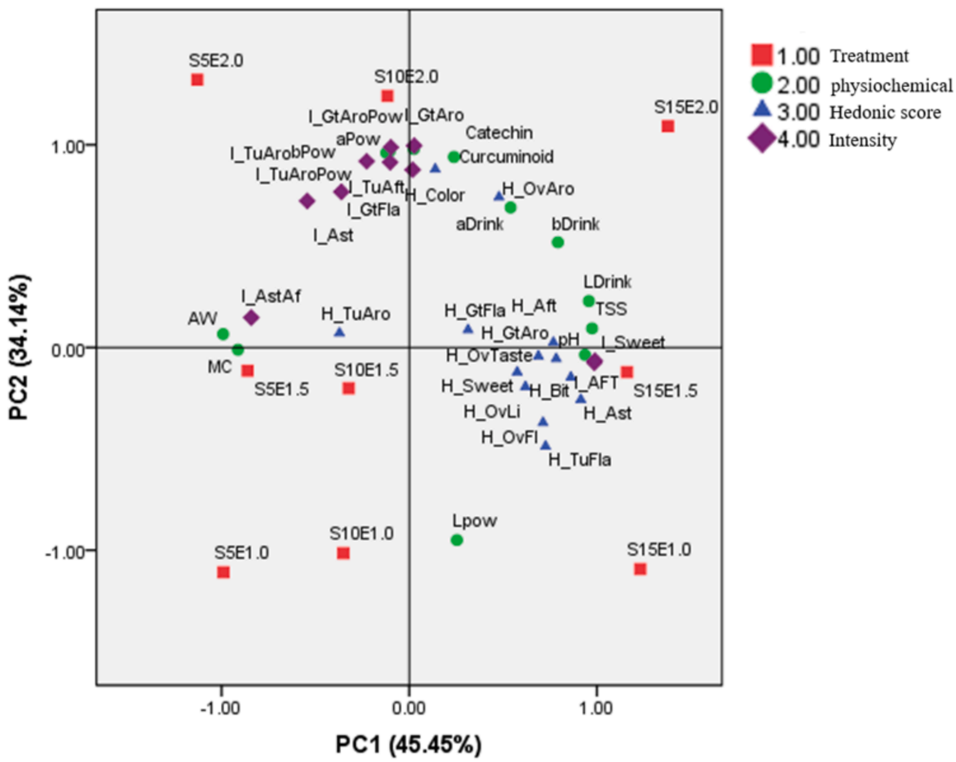

Figure 1. Principal component analysis (PCA) biplot of PC1 and PC2, displaying the direction of the hedonic score and generic descriptive analysis of instant peach drink obtained by different levels of sucrose and COE. Abbreviations: S: Sugar; E: COE; I_: intensity; H_: hedonic score; GT: green tea; TU: turmeric; Aro: aroma; Fla: flavor; Ast: astringent; Aft: Aftertaste; Pow: powder; Ov: overall; Li: liking.

variance (45.5% and 34.1%, respectively), providing a comprehensive multivariate view of the interrelationships between sensory characteristics, consumer responses, and product composition. Formulations containing 15% sucrose and 1.5% COE (S15E1.5) were closely associated with positive consumer hedonic attributes, including sweetness (H_Sweet), overall flavor (H_OvFl), turmeric flavor (H_TuFla), and aftertaste liking (H_Aft). This clustering suggests that this combination achieved the best balance between functional ingredient incorporation and sensory appeal, with high scores in both liking and sweetness while maintaining controlled bitterness and astringency. In contrast, the sample S5E1.5 (5% sucrose, 1.5% COE) was located on the opposite side of the plot, along the negative PC2 axis. It was characterized by high intensities of astringency (I_Ast) and turmeric aroma (I_TuAro), which were not well received by consumers. This distinct separation reinforces the finding that low sucrose levels were insufficient to mask the strong sensory attributes of COE, leading to reduced acceptance across multiple liking dimensions. While earlier sections of the manuscript (i.e., ANOVA results) statistically described the main and interaction effects, this PCA mapping adds a visual and multivariate perspective by showing how sensory, compositional, and liking data align across formulations. It confirms that increasing sucrose not only enhances sweetness and flavor liking but also reduces the negative sensory effects, such as bitterness and astringency particularly when combined with moderate COE concentrations. These findings align with previous studies, which emphasize that consumer acceptance of functional beverages depends not only on health benefits but also on achieving an appealing sensory profile through careful formulation [12,32]. Thus, principal component analysis serves as a valuable tool for visualizing these complex interactions, guiding product development strategies that reconcile bioactive content with market acceptance.

3.5. Practical considerations

These findings highlight a fundamental challenge in developing functional beverages: striking a balance between retaining bioactive ingredients and achieving consumer acceptance. While increasing COE levels up to 2.0% elevated catechin and curcuminoid contents within functional ranges and FDA GRAS limits, it also intensified bitterness and turmeric flavor, resulting in reduced liking scores (Table 4). Interestingly, although the highest COE and sucrose levels reduced undesirable sensory attributes, they did not yield the highest consumer acceptance. The 15% sucrose and 2.0% COE sample exhibited lower bitterness. However, they were still less accepted compared to the formulation with 15% sucrose and 1.5% COE, suggesting that acceptance depends on more than just the suppression of off-flavors. The combination of 1.5% COE and 15% sucrose emerged as optimal, providing approximately 101 mg catechins and 24 mg turmeric per serving sufficient to deliver reported antioxidant benefits [42] while masking undesirable notes and maximizing acceptance, as supported by PCA (Figure 1). This outcome highlights the importance of integrating both sensory descriptive analysis and consumer studies when formulating functional beverages, as lower bitterness does not always translate to higher acceptance. Understanding these interactions is crucial for designing formulations that maintain functionality while preserving palatability. In markets where sensory appeal and health benefits must be carefully balanced, consumers prioritize taste when selecting functional beverages, often over health considerations alone [12,32]. This underscores the need for strategies such as controlled sugar reduction, alternative sweeteners, and advanced encapsulation techniques to retain bioactive efficacy while ensuring consumer preference.

4. Conclusion

This study demonstrated that increasing sucrose levels effectively masked the bitterness and pungency introduced by encapsulated turmeric and green tea extracts (COE) in instant peach drinks, thereby improving consumer acceptance. While higher COE levels enhanced catechin and curcuminoid content, they also intensified undesirable sensory attributes, lowering liking scores. Balancing these factors, a formulation with 15% sucrose and 1.5% COE was identified as optimal, delivering sufficient bioactive levels while maintaining favorable taste. These findings directly address the study's aim of exploring how sucrose and COE concentrations impact sensory perception and acceptance, offering a practical strategy for developing functional beverages that satisfy both health and sensory expectations.

Acknowledgements

The authors gratefully acknowledge Chiang Mai University which enabled the completion of this work. CMU Proactive Researcher, Chiang Mai University [EX010160]. The first author acknowledges RMIT's scholarship support.

CRediT authorship contribution statement

Kanjana Singh: Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Julia Low:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Worrapob Chaisan:** Software, Data curation. **Peeraporn Pakakaew:** Software, Data curation. **Charles Stephen Brennan:** Writing – review & editing, Supervision. **Benu Adhikari:** Writing – review & editing. **Lisa Newman:** Writing – review & editing. **Wilatsana Posri:** Writing – review & editing. **Niramon Utama-ang:** Writing – review & editing, Supervision, Software, Methodology, Investigation, Data curation, 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.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.meafoo.2025.100264.

References

[1] AOAC, Official methods of analysis, 17th ed., The association of official analytical chemists, Gaithersburg, MD, 2000.
[2] Additives, F. (2007). Evaluation of certain food additives and contaminants. In: 2011a.
[3] G. Alharaty, H.S. Ramaswamy, The effect of sodium alginate-calcium chloride coating on the quality parameters and shelf life of strawberry cut fruits, Journal of Composites Science 4 (3) (2020) 123.
[4] A.M. Bakowska-Barczak, P.P. Kolodziejczyk, Black currant polyphenols: Their storage stability and microencapsulation, Industrial crops and products 34 (2) (2011) 1301–1309.
[5] L.M. Bartoshuk, V.B. Duffy, B.G. Green, H.J. Hoffman, C.-W. Ko, L.A. Lucchina, L. E. Marks, D.J. Snyder, J.M. Weiffenbach, Valid across-group comparisons with labeled scales: the gLMS versus magnitude matching, Physiology & behavior 82 (1) (2004) 109–114.
[6] G.K. Beauchamp, Why do we like sweet taste: A bitter tale? Physiology & behavior 164 (2016) 432–437.
[7] A. Belščak-Cvitanović, D. Komes, S. Karlović, S. Djaković, I. Špoljarić, G. Mršić, D. Ježek, Improving the controlled delivery formulations of caffeine in alginate hydrogel beads combined with pectin, carrageenan, chitosan and psyllium, Food Chemistry 167 (2015) 378–386.
[8] P.A. Breslin, An evolutionary perspective on food and human taste, Current Biology 23 (9) (2013) R409–R418.
[9] Y. Choi, R.R. Wong, Y.K. Cha, T.H. Park, Y. Kim, S.-J. Chung, Sweet–bitter taste interactions in binary mixtures of sweeteners: Relationship between taste receptor activities and sensory perception, Food Chemistry 459 (2024) 140343.
[10] M. Cliff, A.C. Noble, Time-intensity evaluation of sweetness and fruitiness and their interaction in a model solution, Journal of Food Science 55 (2) (1990) 450–454.
[11] P. Dalton, N. Doolittle, H. Nagata, P. Breslin, The merging of the senses: integration of subthreshold taste and smell, Nature neuroscience 3 (5) (2000) 431–432.
[12] A. Drewnowski, C. Gomez-Carneros, Bitter taste, phytonutrients, and the consumer: a review, The American journal of clinical nutrition 72 (6) (2000) 1424–1435.
[13] Z. Fan, T. Hasing, T.S. Johnson, D.M. Garner, M.L. Schwieterman, C.R. Barbey, T. A. Colquhoun, C.A. Sims, M.F. Resende, V.M. Whitaker, Strawberry sweetness and consumer preference are enhanced by specific volatile compounds, Horticulture research 8 (2021).
[14] R.A. Frank, J. Byram, Taste–smell interactions are tastant and odorant dependent, Chemical senses 13 (3) (1988) 445–455.
[15] T. Fujimaru, J. Lim, Effects of stimulus intensity on odor enhancement by taste, Chemosensory Perception 6 (2013) 1–7.
[16] A.G. Gous, V.L. Almli, V. Coetzee, H.L. de Kock, Effects of varying the color, aroma, bitter, and sweet levels of a grapefruit-like model beverage on the sensory properties and liking of the consumer, Nutrients 11 (2) (2019) 464.
[17] B.G. Green, J. Lim, F. Osterhoff, K. Blacher, D. Nachtigal, Taste mixture interactions: suppression, additivity, and the predominance of sweetness, Physiology & behavior 101 (5) (2010) 731–737.
[18] E. Guichard, Interactions between flavor compounds and food ingredients and their influence on flavor perception, Food Reviews International 18 (1) (2002) 49–70.
[19] S.C. Gupta, G. Kismali, B.B. Aggarwal, Curcumin, a component of turmeric: from farm to pharmacy, Biofactors 39 (1) (2013) 2–13.
[20] Health, U. D. o., & Services, H. (1998). food and Drug Administration Center for Food Safety and Applied Nutrition (CFSAN). *Guidance for Industry Guide to Minimize Microbiorogical Food Safety Hazard for Fresh Fruit and Vegetables*.
[21] S.J. Hewlings, D.S. Kalman, Curcumin: A review of its effects on human health, Foods 6 (10) (2017) 92.
[22] D.E. Hornung, M.P. Enns, The contributions of smell and taste to overall intensity: A model, Perception & psychophysics 39 (1986) 385–391.
[23] J. Hort, T.A. Hollowood, Controlled continuous flow delivery system for investigating taste− aroma interactions, Journal of Agricultural and Food Chemistry 52 (15) (2004) 4834–4843.
[24] P. Juntasare, Y. Lorjaroenphon, Bitter− masking property of pea eggplant (Solanum torvum Sw.) fruit extract, Food and Applied Bioscience Journal 9 (1) (2021) 1–10.
[25] R. Keast, D. Sayompark, G. Sacks, B. Swinburn, L. Riddell, The influence of caffeine on energy content of sugar-sweetened beverages:'the caffeine–calorie effect, European journal of clinical nutrition 65 (12) (2011) 1338–1344.
[26] R.S. Keast, P.A. Breslin, An overview of binary taste–taste interactions, Food quality and preference 14 (2) (2003) 111–124.
[27] J.H. Kroeze, L.M. Bartoshuk, Bitterness suppression as revealed by split-tongue taste stimulation in humans, Physiology & behavior 35 (5) (1985) 779–783.
[28] N. Laokuldilok, P. Thakeow, P. Kopermsub, N. Utama-Ang, Optimisation of microencapsulation of turmeric extract for masking flavour, Food Chemistry 194 (2016) 695–704.
[29] H.T. Lawless, H. Heymann, Sensory evaluation of food: principles and practices, Springer Science & Business Media, 2010.
[30] J. Lee, E. Chambers Iv, D. Chambers, S. Chun, C. Oupadissakoon, D. Johnson, Consumer acceptance for green tea by consumers in the United States, Korea and Thailand, Journal of Sensory Studies 25 (2010) 109–132.
[31] D.J. Maron, G.P. Lu, N.S. Cai, Z.G. Wu, Y.H. Li, H. Chen, J.Q. Zhu, X.J. Jin, B. C. Wouters, J. Zhao, Cholesterol-lowering effect of a theaflavin-enriched green tea extract: a randomized controlled trial, Archives of internal medicine 163 (12) (2003) 1448–1453.
[32] McDonald, T., Gann, G. D., Jonson, J., Dixon, K. W., Aronson, J., Decleer, K., Hallett, J., Keenleyside, K., Nelson, C., & Walder, B. (2016). International standards for the practice of ecological restoration–including principles and key concepts.
[33] M.C. Meilgaard, B.T. Carr, G.V. Civille, Sensory evaluation techniques, CRC press, 1999.
[34] J.A. Mennella, K.M. Roberts, P.S. Mathew, D.R. Reed, Children's perceptions about medicines: individual differences and taste, BMC pediatrics 15 (2015) 1–6.
[35] A.A. Nolden, G. Lenart, J.E. Hayes, Putting out the fire–Efficacy of common beverages in reducing oral burn from capsaicin, Physiology & behavior 208 (2019) 112557.
[36] R. Pangborn, M. Simone, E. Platou, Natural food flavor intensity: Apricot, peach, and pear nectars studied to determine the sweetness-acid-flavor relationship in a natural food product, California Agriculture 11 (11) (1957) 10. -10.
[37] D. Richter, M. Ekman, F.P. de Lange, Suppressed sensory response to predictable object stimuli throughout the ventral visual stream, Journal of Neuroscience 38 (34) (2018) 7452–7461.
[38] K. Samborska, L. Eliasson, A. Marzec, J. Kowalska, D. Piotrowski, A. Lenart, H. Kowalska, The effect of adding berry fruit juice concentrates and by-product extract to sugar solution on osmotic dehydration and sensory properties of apples, Journal of food science and technology 56 (4) (2019) 1927–1938.
[39] A. Schienle, F. Osmani, C. Schlintl, Disgust propensity and the bitter aftertaste response, Chemosensory Perception 14 (2021) 57–63.
[40] S.S. Schiffman, Taste and smell losses in normal aging and disease, Jama 278 (16) (1997) 1357–1362.
[41] Singh, K. (2023). *Synergistic Effect of Green Tea and Turmeric Extracts on Potential of Anticancer and Its Application of The Encapsulated Ingredients for Health Benefits* Chaing Mai]. online.
[42] K. Singh, B. Adhikari, J. Low, M.A. Brennan, L. Newman, C.S. Brennan, N. Utama-Ang, Development, characterization, and consumer acceptance evaluation of thermally stable capsule beads containing mixed extracts of green tea and turmeric, Scientific Reports 13 (1) (2023) 19299.
[43] C.R. Stampanoni, Influence of acid and sugar content on sweetness, sourness and the flavour profile of beverages and sherbets, Food quality and preference 4 (3) (1993) 169–176.

[44] J. Travers, K. Herman, J. Yoo, S. Travers, Taste reactivity and Fos expression in GAD1-EGFP transgenic mice, Chemical senses 32 (2) (2007) 129–137.
[45] C. Venditti, K. Musa-Veloso, H.Y. Lee, T. Poon, A. Mak, M. Darch, J. Juana, D. Fronda, D. Noori, E. Pateman, Determinants of sweetness preference: a scoping review of human studies, Nutrients 12 (3) (2020) 718.
[46] Q.J. Wang, L.A. Mielby, J.Y. Junge, A.S. Bertelsen, U. Kidmose, C. Spence, D. V. Byrne, The role of intrinsic and extrinsic sensory factors in sweetness perception of food and beverages: A review, Foods 8 (6) (2019) 211.
[47] C.S. Yang, X. Wang, G. Lu, S.C. Picinich, Cancer prevention by tea: animal studies, molecular mechanisms and human relevance, Nature Reviews Cancer 9 (6) (2009) 429–439.
[48] Zellner, D., & Durlach, P. (2003). Effect of color on expected and experienced refreshment, intensity, and liking of beverages.
[49] J. Zokti, A. Badlishah, S. Baharin, S. Abdulkarim, F. Abas, Microencapsulation of green tea extracts and its effects on the physico-chemical and functional properties of mango drinks, Int J Basic Appl Sci 16 (2) (2016) 16–32.