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# Temporal Dominance of Sensations (TDS) of Modern Iced Coffee in a Café Setting

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## ABSTRACT

Coffee consumption in Indonesia has expanded significantly alongside the rapid growth of café culture, creating demand for diverse modern iced coffee offerings. This development highlights the importance of dynamic sensory methods in capturing evolving perceptions in realistic settings. This study characterized the temporal sensory profiles of five modern iced coffee variations-Arabica iced Americano, Arabica iced latte, and three Robusta-based flavored coffee-milks (iced salted caramel, iced Irish, and iced butterscotch)-using the temporal dominance of sensations (TDS) method in a coffeeshop environment. A sensory lexicon was established through a focus group discussion (FGD) with eight consumers and applied in consumer-based TDS evaluations. The results demonstrated distinct sensory dynamics between black coffee and milk-based beverages. Americano was dominated by bitterness and roasted notes, with intermittent acidity. In contrast, flavored coffee-milk samples were consistently characterized by sweetness and chocolate as dominant attributes, resulting in confectionery-like profiles. Multivariate analysis, including a principal component analysis (PCA) that explained 89.46% of the total variance, confirmed two distinct clusters: (1) Americano and latte, characterized by bitterness and roasted notes, and (2) flavored coffee-milks, dominated by sweetness and chocolate. These findings highlight the suitability of TDS for evaluating dynamic sensory changes in café-style beverages, providing practical insights for optimizing recipes optimization and differentiating products in the modern coffee industry.

**Keywords:** coffee shop, dynamic profiles, modern iced coffee, sensory attributes, temporal dominance of sensations (TDS)

## INTRODUCTION

Indonesia is among the world's largest coffee producers and an increasingly important consumer market. The most recent USDA Coffee Annual projects Indonesia's 2025/26 production at 11.3 million 60-kg bags and maintains domestic consumption at 4.8 million bags, reflecting resilient demand despite pressured household spending (USDA, 2025). These figures follow a partial recovery from weather-affected output in 2023/24 and underscore Indonesia's structural role in global supply while its internal market continues to expand. According to the USDA Foodservice (HRI) report compiled with Euromonitor data, cafés/bars outlets increased from 8,057 (2021) to 8,869 (2022) (+10%), with sales up 35% in 2022. The same report documents the rapid expansion of major chains (e.g., Kopi Kenangan from 532 to 932 outlets and Janji Jiwa from 920 to 1,100 between 2021 and 2022), illustrating how routine café visits have become for urban consumers in Indonesia (USDA, 2024). Parallel to this, coffee consumption in out-of-home venues has grown markedly, reflecting a broader shift in consumer preferences towards specialty and cold coffee preparations, which often involve complex flavor profiles that require advanced sensory evaluation techniques (Huang *et al.,* 2023).

Coffee shops offer a wide range of modern coffee beverages ranging from unsweetened espresso-based drinks to milk-based and syrup-flavored iced coffees crafted to deliver layered sensory experiences (bitterness, acidity, sweetness, creaminess, aroma release, cooling, and aftertaste) over the course of consumption. Such diversification heightens the need for robust sensory methods that capture not only which attributes are perceived, but when they dominate during sipping. In Indonesia's café context where iced espresso (e.g., Arabica iced Americano, Arabica iced latte) coexists with flavored milk coffees (e.g., salted-caramel, Irish, butterscotch

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syrup coffee-milk) temporal profiling is especially pertinent because ice dilution, fat content, and aroma taste interactions shift dynamically from first sip to aftertaste, a complex phenomenon where ingredients like milk fat can alter the release and perception of flavors overtime (Thomas *et al*., 2015). Industry data regarding outlet and menu expansion further supports the analytical relevance of temporally resolved sensory data for coffee shop product differentiation and quality control (Frost *et al*., 2020).

Classical sensory approaches have limitations for such dynamic products. Descriptive analysis (DA) yields detailed attribute profiles but is fundamentally static, averaging perceptions over time and obscuring evolution within a sip. Time intensity (TI) can trace temporal curves, but typically for one attribute at a time, burdening assessors and missing competitive interplay among sensations. Check-all-that-apply (CATA) captures attribute incidence but not sequence; its temporal variant (TCATA) records attributes as “on/off” over time, at the cost of a higher cognitive load, and without specifying which sensation is dominant at each moment. By contrast, temporal dominance of sensations (TDS) asks panelists to continuously indicate the single most dominant attribute as perception unfolds. This focus on a single dominant attribute simplifies the cognitive task for panelists, making TDS particularly well-suited for consumer studies where participants have limited sensory training and the goal is to understand the main sequence of sensations (Oliver *et al*., 2018). TDS curves provide a detailed temporal profile of how taste sensations evolve during food consumption, offering insights into the dynamic nature of human perception (Okada *et al.,* 2022). Reviews and comparative studies consistently highlight the strengths of TDS for beverages, including lower task complexity compared to multi-attribute TI/TCATA when the research question targets dominance and temporal structure, sensitivity to formulation and matrix effects, and outputs that are readily interpretable by product developers. Accordingly, applying TDS to modern café beverages can reveal how bitterness, acidity, sweetness, dairy creaminess, and flavor notes (e.g., caramel, butterscotch, Irish-style aromatics) take turns dominating in Arabica iced Americano, Arabica iced latte, iced salted-caramel coffee-milk, iced Irish-syrup coffee-milk, and iced butterscotch-syrup coffee-milk, information directly actionable for recipe optimization and sensory quality management in coffee shops (Castura *et al.,* 2016).

Most TDS applications in coffee research have been confined to laboratory settings and traditional brewing methods, such as black coffee or espresso, focusing primarily on basic sensory attributes like bitterness, acidity, sweetness, and aroma within controlled time frames. These studies have provided valuable insights into sensory dynamics but fail to capture the complex sensory profiles of contemporary coffee beverages served in modern cafés, particularly iced coffee variants that incorporate milk and flavored syrups. Existing literature reveals a significant gap in understanding how the temporal sensory dominance of these multi-component drinks evolves during real-world consumption, where factors such as milk, syrup sweetness, and textural elements interact and potentially alter the sequence and intensity of perceived sensations (Dinnella *et al.,* 2013)

Moreover, most sensory evaluations to date rely on trained panels or controlled laboratory environments, which may not accurately reflect consumer perceptions in naturalistic café settings where environmental variables and consumer expectations influence sensory experience (Frost *et al*., 2020). The dynamic interplay of sensory attributes in modern café-style coffee including the masking or enhancement of flavors by milk and syrups remains underexplored in terms of temporal dominance. Addressing this gap is critical for advancing knowledge of consumer sensory experience and preference formation in popular iced coffee beverages, enabling the coffee industry to tailor products that better meet evolving consumer expectations within authentic consumption contexts.

Previous studies applying TDS to coffee have primarily focused on traditional hot beverages evaluated under controlled laboratory conditions (Dinnella *et al.,* 2013; Oliver *et al.,* 2018; Schlich, 2017). Existing evidence shows that formulation factors such as milk addition and beverage composition significantly influence sensory perception by modifying bitterness, sweetness, and aroma release (Frost *et al.,* 2020; Rashidinejad *et al.,* 2022). However, limited research has investigated the temporal sensory dynamics of modern iced and flavored coffee beverages consumed in real café environments, where temperature, dilution, and complex ingredient matrices may alter dominance patterns over time.

Therefore, this study hypothesizes that milk and flavored syrup additions significantly reshape the temporal dominance structure of iced coffee beverages compared with black iced coffee. Black iced coffee is expected to exhibit sustained dominance of bitterness and roasted attributes, whereas flavored milk-based beverages are anticipated to show prolonged dominance of sweetness and chocolate-related sensations. Multivariate analyses are expected to reveal clear sensory clustering driven by formulation differences. The findings of this research provide practical benefits for society by supporting evidence-based product development and sensory quality optimization within the growing café industry, ultimately helping producers design beverages that better match consumer preferences and improve product consistency.

## MATERIALS AND METHOD

### Materials

Five coffee beverage samples from Faux Society Café (Metro City, Province of Lampung, Indonesia) were evaluated in this study. All samples were variations of iced coffee, including Americano, latte, salted caramel coffee-milk, Irish coffee-milk, and butterscotch coffee-milk. Arabica (scientific name; Bali Belantih origin, Indonesia) and Robusta (scientific name; Lampung origin, Indonesia) coffee beans were utilized in the preparation of the coffee samples; both varieties were sourced from Mulia Roastery (Metro, Lampung). Espresso was obtained from coffee beans milled to a fine particle size utilizing a Compak K3 grinder (Compak Coffee Grinders, Spain). The extraction process differed by variety: for Arabica, 18 g of coffee beans were extracted for 19 s to produce 40 mL of espresso, whereas for Robusta, 18 g of coffee beans were extracted for 23 s to produce 60 mL of espresso. All espresso-based beverages were prepared using a Simonelli Oscar 2 espresso machine (Nuova Simonelli, Italy). An Americano was prepared by mixing 40 mL of espresso extracted from Arabica coffee beans with 100 mL of water and 100 g of ice. An iced latte was prepared by combining 30 mL of Arabica espresso with 160 mL of fresh milk (PT Diamond, Indonesia) and 100 g of ice cubes. A flavored coffee-milk beverage was prepared by blending 17 mL of Robusta espresso, 17 g of creamer (Max Cream, Indonesia), 8 mL of sweetened condensed milk (Frisian Flag, Indonesia), 120 mL of UHT milk (Diamond, Indonesia), and 100 g of ice cubes. Finally, 20 mL of flavored syrup (salted caramel, Irish, or butterscotch) was incorporated into the beverage formulation.

Arabica beans were used for the Americano and latte to provide a profile charac-terized by nuanced acidity and aroma, typical of these classic beverages. In contrast, Robusta beans were used for the flavored coffee-milk drinks. This choice was based on common industry practice, where the higher bitterness and bold character of Robusta provide a strong coffee base that is not completely masked by the addition of milk, creamer, and flavored syrups.

The research was divided into three stages; the first stage involved selecting panelists who regularly visit the Faux Society coffee shop at varying frequencies. The second stage involved imple-menting focus group discussions (FGD) with panelists to develop terms for each attribute. The third stage focused on sample testing using the TDS method with consumer panelists for time-based characteristics.

### Panelists

FGD were conducted with six heavy consumers from Faux Society, Metro, Lampung (aged 20–30 years), to produce sensory descriptors, following the approach. Panelists were selected from the coffee shop's regular clientele to ensure they were familiar with the product category of modern iced coffee, thus providing a relevant and informed initial lexicon. Participants consisted of non-expert individuals with no formal training in sensory evaluation. They were familiarized with the TDS tasks before the experiment until they felt confident. This suggests that prior experience and training can influence an individual's ability to perform TDS tasks (Natsume *et al.,* 2023). Panelists were trained twice to effectively describe the sensory attributes. TDS requires panelists to select the dominant attribute from a list at each moment during tasting. This forced-choice approach can lead consumers to select the attribute they are most confident about, irrespective of the definition of 'dominance' provided. This introduces a subjective element that can impact the interpretation of results (Visalli *et al*., 2023). This approach was deemed appropriate for the exploratory phase of generating sensory attributes. After consolidation, these attributes were refined into five sensory categories: appearance, aroma, texture, taste, and aftertaste. The number of panelists and selection criteria were based on the Indonesian National Standard (SNI 01-2346-2006), which requires a minimum of six trained panelists. This study was conducted with human ethics approval No.1990/IT3.KEPMSM-IPB/SK/2025.

### Sample preparation

The five iced coffee samples consisted of Americano, latte, salted caramel coffee-milk, Irish coffee-milk, and butterscotch coffee-milk. They were given random codes 111, 904, 573, 828, and 651. Each sample was served in a 300 mL cup with a portion size of 30 mL per sample. Immediately before consumption, 20 g of ice cubes were added. Mineral water was also provided as a palate cleanser.

FGD were conducted to explore the emotional responses elicited by the product as well as consumers' perceived differences among the samples (Gunaratne *et al.,* 2019). In total, six consumers participated in the FGD, each lasting approximately 20–30 min. During the sessions, participants were asked to evaluate each sample individually and to articulate the sensory attributes they perceived. Within a structured framework guided by the moderator, participants were encouraged to share their perspectives, with the elicited taste-related attributes primarily emerging from spontaneous group discussion.

**Temporal dominance of sensations (TDS) procedure**

The TDS test was conducted based on the methodology described in Dinnella *et al*. (2013), with modifications. Attributes used in this test were based on FGD results. The TDS test was conducted on the same day and in the same digital questionnaire link by RedJade (RedJade Sensory Solutions, USA).

During the testing session, panelists were asked to drink the coffee sample and click the 'MULAI (START)' icon. Panelists were instructed to hold the sample in their mouth for 5 s before swallowing to standardize the initial evaluation phase across all participants. This ensures that the initial dominance ratings are based on a comparable oral exposure time before the complex dynamics of swallowing and aftertaste perception begin. After the 5th second, panelists were allowed to swallow the sample. To evaluate the dominance of attributes in the sample, panelists could simply click the attribute icon that they perceive as dominant. Panelists were allowed to change their perceived dominant attribute if the time was still running. If the panelists do not perceive any other attributes, panelists may click the 'STOP' button to end the evaluation of the sample. The TDS evaluation was conducted within the coffee shop to maximize ecological validity. To minimize distractions, panelists were situated in a quieter section of the establishment, and testing was scheduled during off-peak hours. While uncontrolled environmental factors remain a limitation of this in situ approach, it offers a more realistic assessment of sensory perception compared to a sterile laboratory environment.

**Data analysis**

Data obtained from the TDS test were processed using sensory analysis–TDS feature in XLSTAT (Lumivero, USA). The analysis results produced TDS curves and attribute band graphs for every significant attribute in each sample. The TDS curve displays the dominance percentage over time for all attributes tested in the samples. The band's graph, however, only visualizes the significant attributes based on panelists' perception over the tasting time. Attributes are considered to be dominant if the percentage of dominance has reached above the significance limit, computed by XLSTAT. The chance limit is the dominance rate limit that an attribute can obtain by chance or random selection (Schlich, 2017). This represents the dominance rate an attribute might obtain purely by chance, calculated as 1 divided by the number of attributes (González-Mohino *et al*., 2021). The chance limit is computed based on the following calculation (Equation 1).

$$\text{Chance of Limit} = \frac{1}{\text{number of attributes}} \quad \ldots\ldots\ldots\ldots (1)$$

TDS data were also analyzed with a cumulative dominance time (CDT) approach, based on Saita *et al*. (2021). Significance was determined at $p<0.05$. CDT is counted from the total 'dominant' response duration of each attribute in the sample from all panelists. CDT values for each attribute in all samples were then analyzed with the Kruskal-Wallis non-parametric test to analyze the impact of sample differences on CDT values. Principal component analysis (PCA) and agglomerative hierarchical clustering (AHC) cluster were also done to map or visualize the attributes' dominance and the samples in the form of a clustered biplot.

## RESULTS AND DISCUSSION

**Results of the focus group discussion**

The lexicon was developed through a discussion to generate more attributes, which was done after the testing of each brew sample. During the FGD, a lexicon containing 31 attributes and their corresponding references was provided to the panelists. The lexicon comprised five taste attributes (T), ten flavor attributes (F), six aroma attributes (A), two color attributes (C), three mouthfeel attributes (M), and four aftertaste attributes (AT), as presented in Figure 1 and Table 1. Since the attributes were going to be included in all series of tests, the generated attributes were then reduced to fit in the ideal requirement for TDS testing of fewer than 12 attributes (Schlich, 2017).

During the attribute reduction phase, panelists converged on six key terms that they felt were the most essential for differentiating the five samples. While a broader lexicon of 31 attributes was initially generated, attributes such as 'caramel flavor,' 'buttery,' and 'nutty' were deemed by the group to be sub-components or less frequently dominant compared to the overarching sensations of 'sweetness' and 'chocolate flavor' in the flavored milk coffees. To adhere to TDS best practices of avoiding cognitive overload and focusing on the most dominant attributes, the group agreed to collapse these specific notes into broader, more consistently dominant categories for the initial TDS task. All four taste attributes in the provided lexicon were already pre-determined for testing; hence, panelists were only able to reduce the flavor attributes. At the end of FGD, two attributes were jointly agreed among the panelists. The specific attributes chosen for evaluation in a TDS study directly influence the resulting curves. A comprehensive and relevant list of attributes is crucial for capturing the full sensory experience (Correia *et al*., 2022). These attributes include four pre-determined taste attributes: roasted flavor and chocolate flavor. Table 1 summarizes the development of the lexicon during FGD.


Figure 1. Sensory wheel of coffee-based menu at Faux Society

Table 1. Lexicon development during focus group discussion (FGD)

| Lexicon Provided | Lexicon Generated during FGD | Lexicon Agreed during FGD |
|---|---|---|
| Bitter taste (T) | Bitter taste (T) | Bitter taste (T) |
| Sweet taste (T) | Sweet taste (T) | Sweet taste (T) |
| Sour taste (T) | Sour taste (T) | Sour taste (T) |
| Salty taste (T) | Salty taste (T) | Salty taste (T) |
| Caramel flavor (F) | Umami taste (T) | Roasted flavor (F) |
| Milk flavor (F) | Biscuit flavor (F) | Chocolate flavor (F) |
| Roasted flavor (F) | Roasted flavor (F) | |
| Fermented flavor (F) | Milk flavor (F) | |
| Creaminess mouthfeel (M) | Caramel flavor (F) | |
| | Fermented flavor (F) | |
| | Vanilla flavor (F) | |
| | Nutty flavor (F) | |
| | Buttery flavor (F) | |
| | Chocolate flavor (F) | |
| | Fruity flavor (F) | |
| | Caramel aroma (A) | |
| | Buttery aroma (A) | |
| | Fruity aroma (A) | |
| | Nutty aroma (A) | |
| | Fermented aroma (A) | |
| | Milk aroma (A) | |
| | Black color (C) | |
| | Brown color (C) | |
| | Creaminess mouthfeel (M) | |
| | Light mouthfeel (M) | |
| | Thick mouthfeel (M) | |
| | Bitter aftertaste (AT) | |
| | Sour aftertaste (AT) | |
| | Sweet aftertaste (AT) | |
| | Oily aftertaste (AT) | |

**Sensory profile map based on TDS–curves and bands method**

The TDS data are analyzed in XLSTAT, and the curves, chance limits, and significance limits are shown in Figure 2. The chance limit is the dominance rate limit that an attribute can obtain by chance or random selection (Schlich, 2017). This represents the dominance rate an attribute might obtain purely by chance, calculated as 1 divided by the number of attributes (González-Mohino *et al*., 2021). The chance limit is computed based on the following calculation (Equation 2).

$$\text{Chance of Limit} = \frac{1}{\text{number of attributes}} = \frac{1}{6} = 0.167 \quad (2)$$

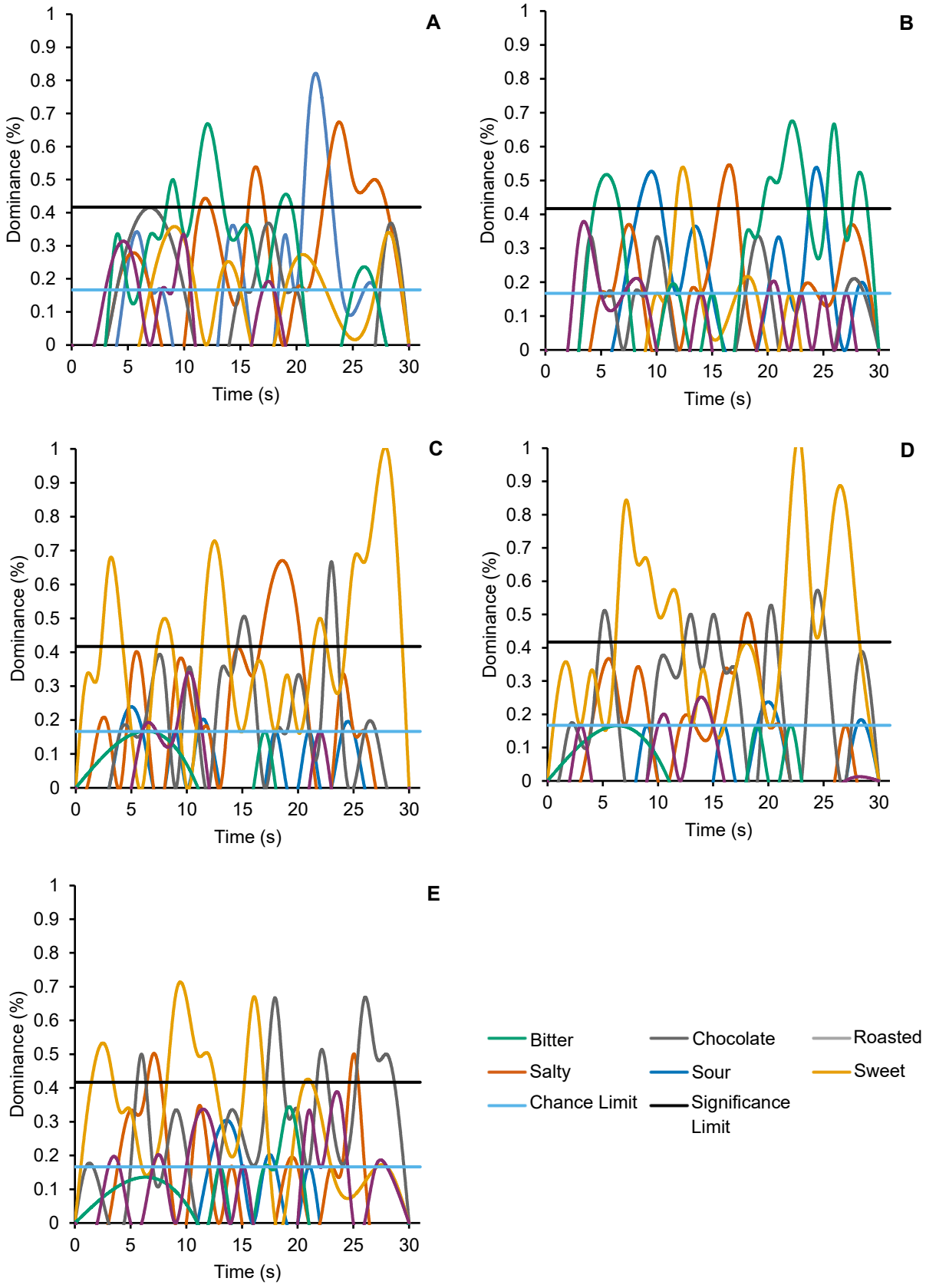
Meanwhile, the significance limit is the minimum dominance rate for an attribute to be considered significant (Schlich, 2017). The significance limit is computed using the binomial test by XLSTAT with n= 5 and $\alpha$= 0.05. The significance limit obtained is 0.417, meaning only attributes with a dominance rate beyond 0.417 can be considered significantly dominant.

The TDS profiles of the five iced coffee beverages reveal apparent differences in sensory dynamics influenced by product formulation and flavor addition. In Iced Americano, bitterness emerges as the first and most dominant attribute, followed by roasted notes and intermittent sourness. A similar dominance of bitterness in black coffee beverages has been reported in previous sensory studies, where bitterness and roasted attributes were identified as the primary drivers of coffee perception (Dinnella *et al.,* 2013; Frost *et al.,* 2020). This similarity suggests that the absence of milk or sweeteners allows the inherent bitter compounds of coffee to dominate the sensory profile. In an iced latte, the sensory experience is more balanced, where initial bitterness is rapidly replaced by sweetness and chocolate notes. This observation aligns with findings from Rashidinejad *et al.* (2022), who reported that milk proteins and fats interact with coffee polyphenols and reduce perceived bitterness. As a result, sweet and creamy attributes tend to dominate the sensory profile in milk-based coffee beverages.

Bitterness is perceived at the onset but quickly gives way to sweetness, which dominates for most of the evaluation period. Chocolate notes appear in the middle to later stages, contributing to a smooth and creamy impression. Unlike an iced Americano, the roasted flavor is less evident, showing that milk addition in cold coffee reduces sharp notes and enhances mildness; this is a well-documented effect where milk proteins and fats bind to phenolic compounds responsible for bitterness and astringency, thereby suppressing their perception and altering the overall flavor profile (Rashidinejad *et al.,* 2022; Tang *et al.,* 2024).

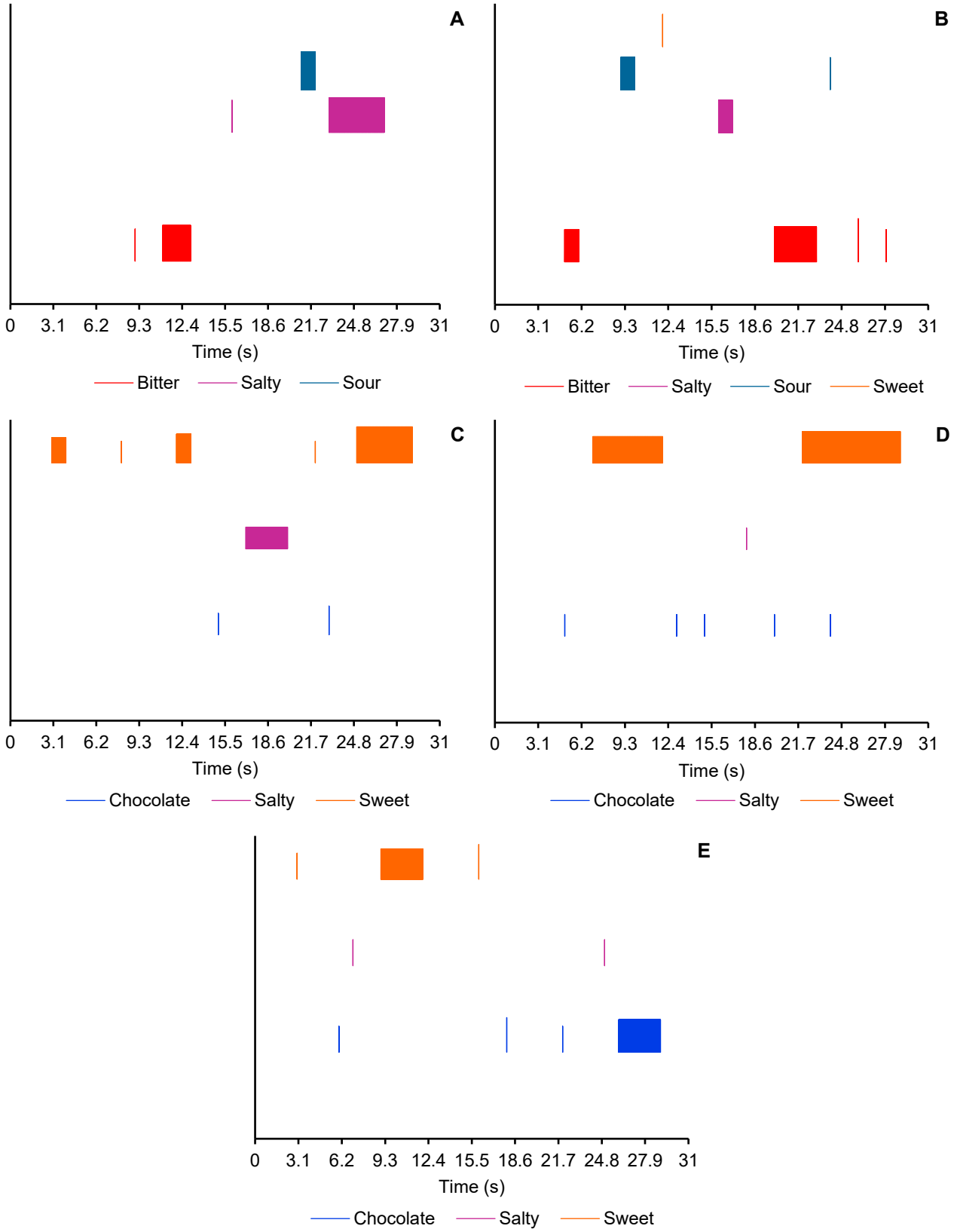
The salted caramel coffee-milk shows sweetness as the most consistently dominant attribute throughout the perception timeline. Similar dominance of sweetness has been observed in flavored coffee beverages where added syrups and dairy components enhance sweet perception and mask bitter compounds (Tang *et al.,* 2024). This masking effect explains why bitterness becomes less prominent in flavored coffee-milk formulations compared to black coffee beverages. This is supported by secondary chocolate notes and occasional salty impressions, which together create a layered and indulgent flavor profile. Bitterness, in contrast, plays only a minor role, indicating that caramel flavoring masks harsher attributes and enhances confectionery-like sensations. A similar trend is found in Irish coffee-milk, where sweetness dominates throughout, with chocolate notes emerging strongly and persistently. The overall profile is smooth and creamy, with bitterness making a minimal contribution to the experience. Compared to the other flavored coffees, Irish coffee-milk delivers a richer and more rounded perception, emphasizing dessert-like qualities. Finally, butterscotch coffee-milk is characterized by a strong sweetness dominance, consistently supported by chocolate notes throughout the evaluation. Roasted impressions are present but weaker, and both sourness and bitterness remain minimal. The overall sensory experience is mild, creamy, and strongly aligned with confectionery characteristics, making it one of the smoothest flavor profiles among the samples.

The significant attributes in each second for a sample were then displayed in a band plot, as shown in Figure 3. TDS band plots emphasize when an attribute is significantly dominant, unlike the previous curve plots that showed dynamic fluctuations in dominance. These band plots allow more precise identification of specific sensory attributes at intervals. The TDS band profiles provide a complementary perspective to the curve plots by showing clearly defined periods when specific attributes are significantly dominant. The TDS analysis utilized curve and band visualizations to provide a comprehensive understanding of sensory dynamics in iced coffee beverages. The curve profiles captured the continuous fluctuations of attribute dominance throughout consumption, while the band profiles highlighted specific time intervals where attributes reached significant dominance. Together, these two perspectives enhance the understanding of sensory perception across various beverage formulations.




Note: Americano (A), iced latte (B), salted caramel coffee-milk (C), Irish coffee-milk (D), butterscotch coffee-milk (E)

Figure 2. Temporal dominance of sensations (TDS) curves of five variants of coffee beverages




Note: Bands by attribute in Americano (A), iced latte (B), salted caramel coffee-milk (C), Irish coffee-milk (D), butterscotch coffee-milk (E)

Figure 3. Temporal dominance of sensations (TDS) band of five variants of coffee beverages

In iced Americano, the curve plots revealed bitterness as the earliest and most dominant sensation, followed by roasted notes and intermittent sourness. The band profiles validated this observation by showing clear dominance of bitterness in the middle stage of consumption, with sour and salty attributes appearing in later intervals. This confirms that iced Americano maintains a sharper and more intense sensory character, with bitterness and acidity as defining attributes. For the iced latte, the curves illustrated an initial perception of bitterness that was quickly overtaken by sweetness and chocolate, producing a smoother profile. The band plots supported this finding by showing repeated intervals of sweetness dominance and stable chocolate impressions, while roasted flavor was largely absent. This demonstrates that the addition of milk not only reduces the intensity of bitterness and enhances mildness, but also allows sweet and creamy notes to dominate the sensory experience. TDS curves provide a clear, time-based visual representation of how different sensory attributes evolve and dominate during the consumption of a food item, enabling detailed analysis of dynamic sensory experiences (Natsume and Okamoto, 2024).

The salted caramel coffee-milk showed sweetness as the consistently dominant attribute across the curve plots, accompanied by chocolate and occasional salty notes. The band visualization reinforced this result, with multiple significant sweetness dominance intervals complemented by short chocolate and saltiness periods. These findings highlight the indulgent and layered nature of caramel-flavored iced coffee, where sweetness is persistent while salt and chocolate contribute to complexity. A similar pattern was observed in Irish coffee-milk, where the curve profiles showed an intense and persistent dominance of sweetness with chocolate emerging consistently. The band plots confirmed this by displaying long, uninterrupted intervals of sweetness, accompanied by repeated chocolate impressions. Compared to salted caramel, Irish coffee-milk presented a more stable sweet dominance, further emphasizing its rounded and dessert-like sensory qualities.

Finally, the curves characterized butterscotch coffee-milk by alternating dominance between sweetness and chocolate, with minimal bitterness or sourness. The band profiles validated this by showing precise intervals of sweetness in the early stages and chocolate dominance later, creating a layered yet mild perception. This confirms that butterscotch-flavored iced coffee delivers one of the samples' creamiest and most confectionery-like profiles. The temporal sensory profiles of products are indeed highly dependent on the raw material, brand-specific formulations, and processing techniques. These factors collectively determine the dominant tastes and how these tastes evolve during consumption (Gaider and Majchrzak, 2024).

Overall, both curve and band representations converge on the same conclusion: iced black coffee (Americano) is characterized by bitterness and sharper attributes, while iced milk-based flavored coffees (latte, salted caramel, Irish, and butterscotch) are dominated by sweetness and chocolate notes. The curve profiles provided a dynamic picture of sensory transitions. In contrast, the band profiles clarified the precise dominance intervals, offering a comprehensive understanding of temporal sensory perception in iced coffee beverages. Sensory analysis with Temporal Dominance of Sensations provides insights into the taste and flavor dynamics of coffee and other food samples, from a multi-dimensional and temporal perspective (Schlich, 2017). The changing dominance over time, as seen in Figures 2 and 3, confirms the understanding that taste and flavor perceptions are a function of time due to the dynamic nature of their sensory process. When coffee is consumed, volatile compounds in the brewed coffee are first diluted with saliva and transported from their liquid phase to the air phase in the mouth before finally reaching the olfactory receptors in the nose (Foster *et al*., 2011). The interaction with other compounds in the matrix, such as taste-active compounds, also influences the release of volatile compounds from the liquid matrix. Huang *et al*. (2023) stated that components of the matrix that taste buds can perceive could influence the saliva–air partition of aroma compounds by altering physical and chemical conditions in the saliva phase. Complex phenomena occurring in the mouth, such as saliva production and mastication, as well as the synergy of taste sensations, contribute to the subjective sensory experience and how dominant tastes are perceived temporally. The dominant taste profile of coffee is primarily influenced by the specific sensory profile inherent to each product, resulting in distinct temporal evolutions of attributes such as sourness and bitterness. While the study controlled for many variables, individual physiological responses and environmental factors can also influence the temporal perception of taste (Natsume and Okamoto, 2025).

**Cumulative dominance time (CDT)**

Another approach to TDS data interpretation was conducted using CDT, which quantifies the total duration during which each attribute is perceived as dominant throughout the evaluation period (Saita *et al.,* 2021). CDT values for all attributes across the five coffee samples are presented in Table 2.

Table 2. Cumulative dominance time (CDT) of five variants of coffee beverages

| Sample | Sweet | Salty | Sour | Bitter | Roasted | Chocolate |
|---|---|---|---|---|---|---|
| Americano | 22.098 | 35.619 | 23.644 | 38.497 | 8.246 | 14.870 |
| Latte | 17.057 | 25.337 | 31.042 | 23.511 | 14.905 | 17.386 |
| Salted caramel | 66.835 | 38.335 | 7.474 | 1.947 | 7.961 | 29.753 |
| Irish | 78.301 | 24.227 | 6.394 | 1.745 | 6.492 | 37.954 |
| Butterscotch | 56.114 | 24.545 | 7.007 | 6.156 | 17.272 | 45.533 |

This approach allows a quantitative comparison of sensory dominance patterns between products and has been widely applied in temporal sensory studies to complement graphical TDS interpretations. The CDT results revealed clear differences between black coffee and flavored coffee-milk beverages. Americano and iced latte showed higher cumulative dominance of bitterness and roasted attributes, whereas the flavored coffee-milk samples were dominated by sweetness and chocolate attributes. A similar shift in sensory dominance has been reported in previous studies where the addition of milk and sweeteners reduced bitterness perception and increased the prominence of sweet and creamy attributes in coffee beverages (Rashidinejad *et al.,* 2022; Tang *et al.,* 2024). These findings suggest that formulation components such as milk fat and added syrups modify the temporal perception of coffee by masking bitter compounds and enhancing sweetness-related sensations.

To further explore these relationships, PCA was performed using CDT values to visualize the association between samples and sensory attributes. PCA is commonly used in sensory science to simplify complex multivariate datasets and identify the main drivers of product differentiation (Peltier *et al.,* 2023). Individual characteristics of panelists significantly influence the TDS data, affecting both the duration of perceived dominant attributes and the overall sensory experience of a product (Kurata *et al*., 2021).

The first two principal components, F1 and F2, have eigenvalues above 1 and account for a cumulative variability of 89.46%, indicating that both F1 and F2 effectively capture most of the data variance and reduce data dimensionality. The dimensional reduction effectively captured the main variability within the dataset. The multivariate analysis provided further validation of these sensory trends. Agglomerative hierarchical clustering identified two distinct clusters, as seen in Figures 4 and 5. The AHC dendrogram divided the products into two major groups: Americano and latte (cluster 1); and butterscotch, salted caramel, and Irish coffee-milk (cluster 2). This clustering pattern reflects the fundamental formulation differences between unsweetened coffee beverages and sweetened milk-based products. Similar clustering behavior has been reported in sensory studies of flavored beverages, where sweetness-driven attributes separate milk-based formulations from traditional coffee profiles (Dinnella *et al.,* 2013). This separation also indicates a fundamental sensory contrast between black/milk coffee beverages and flavored coffee-milk products. cluster 1 was characterized by the dominance of bitterness, acidity, and roasted attributes, while cluster 2 was marked by sweetness and chocolate sensations. These groupings are closely aligned with the temporal profiles observed in TDS, confirming the distinct sensory identity of each product group.

The AHC grouped Americano and latte (cluster 1), underscoring the critical limitation of relying solely on cumulative dominance time. The clustering was driven by the shared presence of bitterness and roasted notes, which distinguished them from the heavily sweetened flavored coffees. However, the TDS curves clearly demonstrate that the sensory journey of a latte is fundamentally different from that of an Americano. In latte, bitterness is a fleeting initial note, quickly replaced by a sustained dominance of sweetness and chocolate. While both beverages contain these notes, the TDS curves clearly show their temporal roles are fundamentally different. In Americano, bitterness is sustained, whereas in latte, it is a fleeting initial note immediately superseded by a lasting dominance of sweetness. Therefore, while CDT is useful for quantifying the total time an attribute is dominant, it can obscure the sequential dynamics that define a product's sensory journey. The latte profile illustrates that it is not simply an 'Americano with milk' but a distinct experience, occupying a transitional sensory space not fully captured by the static CDT-based clustering. This highlights a limitation of clustering based on cumulative dominance time alone. At the same time, latte shares some base attributes with Americano, the temporal dynamics and overall profile are significantly moderated by the milk, placing it in a transitional position between black coffee and flavored-milk coffees.

The PCA further explained the sensory drivers of this clustering by capturing 89.46% of the total variance on the first two dimensions (F1= 61.05%; F2= 28.41%). Americano and latte were positioned close to bitterness, acidity, and roasted notes, validating their placement in cluster 1.

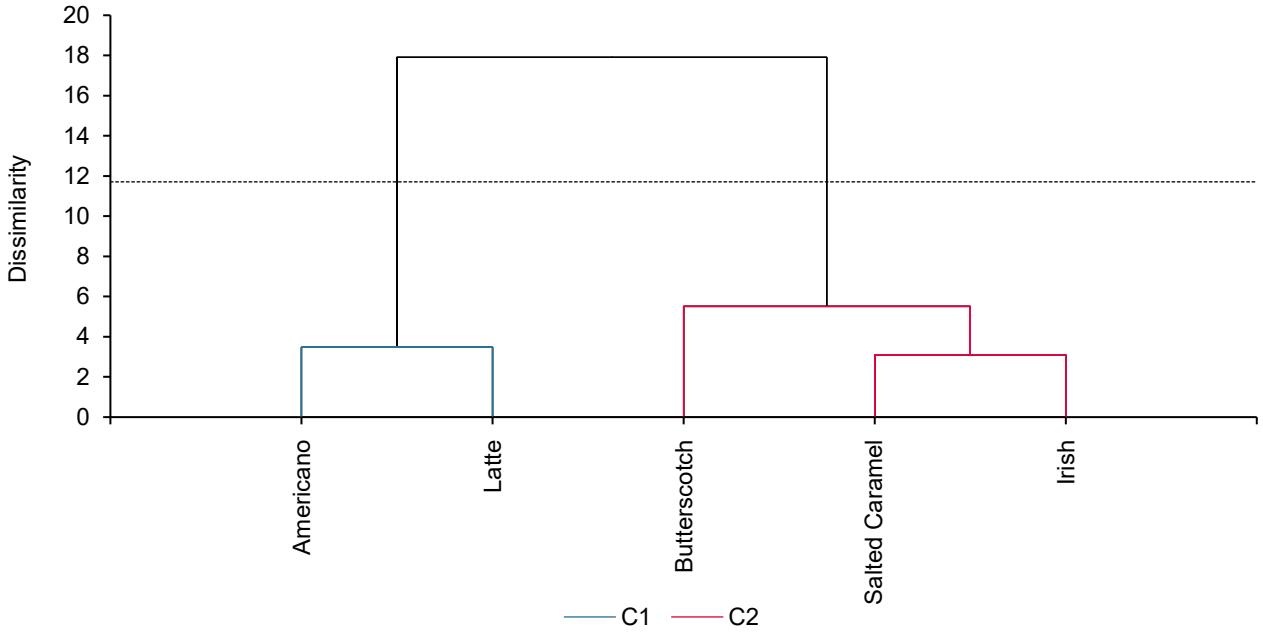



Figure 4. Agglomerative hierarchical clustering (AHC) cluster diagram of samples based on TDS-CDT

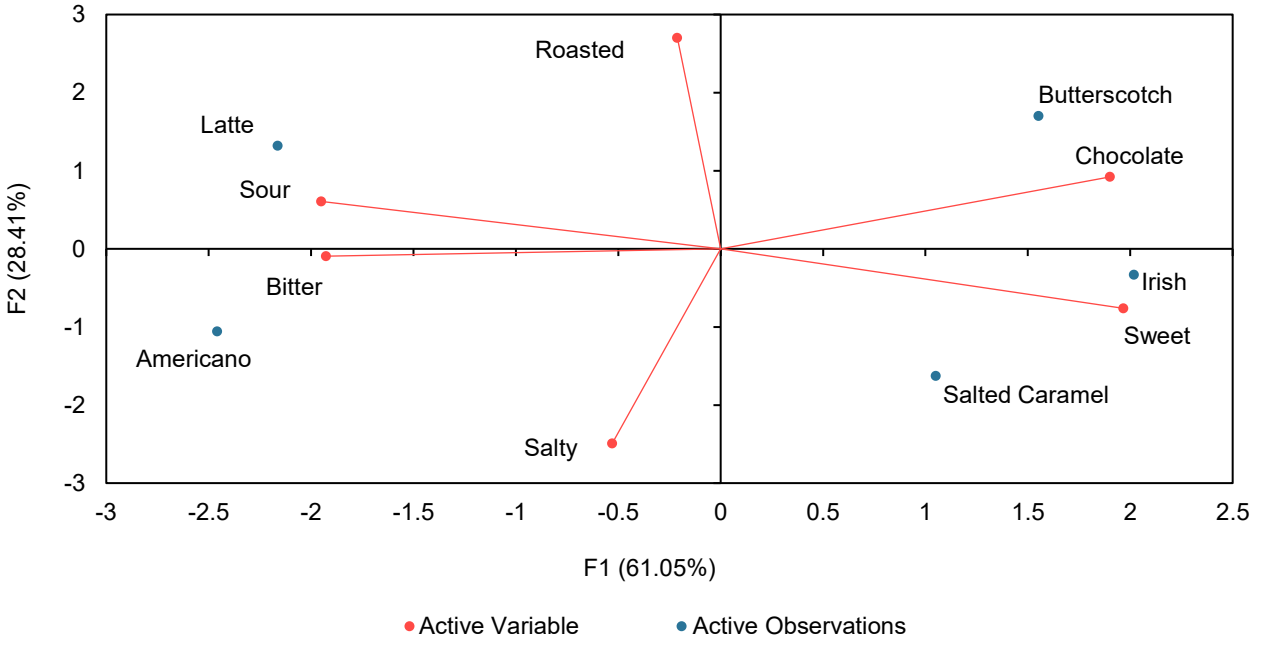



Figure 5. Biplot profile map of samples and attributes based on TDS-CDT (axes F1 and F2: 89.46%)

Butterscotch, salted caramel, and Irish coffee-milk aligned with sweetness and chocolate in cluster 2. Among the flavored samples, butterscotch was the most closely associated with chocolate, Irish was perceived as sweet, and salted caramel was positioned between the two, reflecting its balanced sensory profile. The PCA and AHC results confirmed the temporal dominance findings. They highlighted how product differentiation is driven by specific sensory attributes that structure consumer perception across time and intensity dimensions.

## CONCLUSION

The application of the temporal dominance of sensations (TDS) method successfully revealed the temporal evolution of sensory attributes in modern iced coffee beverages under realistic café conditions. Black coffee beverages such as Americano were characterized by dominant bitterness, acidity, and roasted notes, whereas milk-based flavored coffees demonstrated confectionery-like profiles dominated by sweetness and chocolate. Multivariate analyses

(CDT, PCA, and AHC) consistently distinguished two major clusters aligned with these sensory patterns, underscoring the influence of milk and syrup formulations on temporal sensory perception. These results extend the application of TDS beyond traditional black coffee to flavored iced beverages, providing actionable insights for product innovation, recipe optimization, and quality management in the coffee industry.

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