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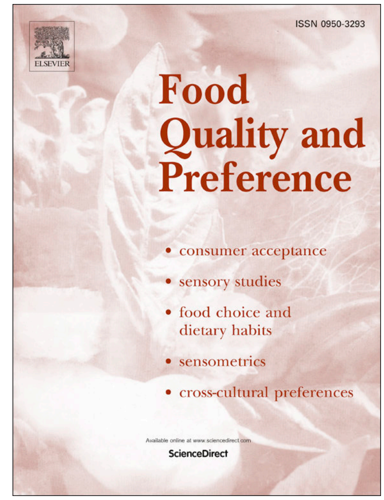

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The combined use of temporal dominance of sensations (TDS) and discrete time-intensity (DTI) to describe the dynamic sensory profile of alcoholic cocktails

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Abstract

Time Intensity (both continuous-TI and discontinuous-DTI) and Temporal Dominance of Sensations (TDS) represent the main methodologies for describing the temporal evolution of the different sensations developing during food consumption. Sensory description from these methods relies on different aspects of perception, time-intensity covers the time course of selected sensation intensity while TDS describes the profile in terms of dominant sensations and their temporal sequence. Data collection on both these aspects would provide a more comprehensive description of the dynamic sensory profile. In this work, a new approach combining TDS and DTI methodologies is presented with the aim to: 1) describe the time course of dominant sensations and their relevant intensities in alcoholic beverages; 2) propose new graphical tools to facilitate the observation of changes in the intensities of dominant sensations over time within and between products. The TDS profile of alcoholic cocktails was described by trained assessors. TDS curves of each product were visually inspected, the significantly dominant attributes were selected considering three evaluation intervals: attack 0-30 sec; evolution 31-60 sec; finishing 61-90 sec. Meaningful points for intensity evaluation were identified considering the times at which the dominant attributes were close to their maximum DR value in each time interval. The same panel was further trained to perform the DTI task consisting in the evaluation of the intensity of the dominant attributes at the selected time points. The proposed approach described the product dynamic profiles in terms of the time course of dominant attributes intensities. The dynamic spider plot was proposed as a new graphic representation to illustrate and compare the evolution of the intensity of dominant attributes along attack, evolution, and finishing within and across products.

Keywords: dynamic sensory profile, Temporal Dominance of Sensation (TDS), Discrete Time-Intensity (DTI), alcoholic cocktails, Spritz

1.Introduction

Sensory properties play a key role in the overall quality of food and beverages, and in influencing consumer preference. Static methods have been extensively applied to describe the sensory profile of food products, but the process of tasting food is a complex dynamic process where the perception of aroma, taste, and texture changes over time (Lawless & Heymann, 1999). Furthermore, Dijksterhuis & Piggott (2001) pointed out that the timely release of flavors and tastes during eating and drinking plays an important role in food appreciation. Therefore, by the use of static methods, some relevant information could be missed. To overcome this limitation several temporal sensory methods have been developed for the study of the temporal evolution of the sensory properties of food products.

Temporal sensory methods evolved starting from Time-intensity (TI) (Lee & Pangborn, 1986) to Temporal Dominance of Sensations (TDS) (Pineau et al., 2009) and more recently to Temporal Check All That Apply (TCATA) (Castura et al., 2016).

TI tracks the evolution of the intensity of one or more sensory descriptors over time. The main disadvantage of the TI technique is that it becomes very time consuming when it is used for several attributes because one run is needed for each attribute (Monteleone & Dinnella, 2017; Pineau et al., 2009). One possibility to avoid these limitations is to use methodologies that allow the scaling of different attributes during the time course of the sensory evaluation. In Discrete Time Intensity (DTI) approach panelists are asked to rate the intensity of one or several attributes at pre-determined time intervals, thus allowing the description of the temporal evolution of several sensations at the same time. Attributes can be different for each point over the same evaluation. DTI is used to evaluate perceptual changes occurring over time after a single or repeated exposure to a product. The intensity is sampled at "meaningful" time intervals which may vary in interval length and frequency, for example at distinct phases of eating (bite, chewing, swallowing) or at time points at which sensory changes related to product acceptance are likely to occur. DTI method reduces the halo-dumping effect as demonstrated by their pioneering work by Clark & Lawless (1994), lowers the number of runs needed to obtain the temporal information but tracks a less detailed pattern of time-related sensory changes (Kuesten, 2017 for review). Changes occurring in food and oral environment during mastication are possible criteria to identify "meaningful" time during consumption for intensity ratings. For example, DTI methodology has been proposed to track the evolution of intensity of food sensory properties at preselected times during mastication cycles and explores its possible association with the release of sensory active molecules, and interindividual variability in oral measurements (Pionnier et al., 2004), ethnicity and gender (Pedrotti et al., 2019). DTI principle has been applied in Multi Attribute Time Intensity (MATI) methodology to track the evolution of the intensity of sensory attributes at different consumption stages (from the first bite to the "residual" after swallowing) adopting a paced intensity rating for all attributes relevant to the specific consumption stage (Kuesten et al., 2013, Kuesten and Bi, 2018).

TDS is a multi-attribute method aimed at tracking the sequence of "dominant" sensory attributes during consumption. The dominance construct has not reached agreement on its exact definition (Schlich, 2017; Varela et al., 2018). The dominant attribute has been defined as "*the most intense sensation*" (Labbe et al., 2009; Albert et al., 2012), the one that "*triggers the most the attention at a point in time*" (Lenfant et al., 2009), "*the sensation catching the attention of the assessors at a given time, not necessarily being the one with the highest intensity*" (Bruzzone et al., 2013) or *"the new sensation popping up, not necessarily the most intense*" (Pineau et al., 2009; Rodrigues et al., 2016a). Thus, different aspects of sensory perception (sensation intensity, attentional capture, and sensory changes during consumption), all contribute to the dominance definition. In TDS studies, panelists are presented with a list of attributes and are asked to choose the "dominant" sensations at any time over the evaluation. TDS results are presented as an average dominance curve that is the proportion of assessors reporting the attribute as dominant at any given time.

The original versions of DTI and TDS are based on the response of trained assessors and require quite demanding procedures in terms of time and effort to train the panelists. In general, assessors need to be trained in both the method itself and in the evaluation of specific sensations. The phase of descriptive term generation and the consensus on descriptor definition are included in the training procedure, depending on the panel's familiarity with the product under investigation.

The most important feature of DTI and TDS methods is the collection of highly detailed information and the description of subtle changes in product sensory dynamic profile. This information has several important practical applications. In product development and innovation, these methods help the investigations of the impact on sensory properties of formulation changes adopted to meet consumer expectations for food pro-healthy properties, such as reduced sugar and sodium chloride content (da Silva et al., 2014; de Souza et al., 2013; Feltrin et al., 2015; Morais et al., 2014; Parker et al., 2018; Paulsen et al., 2014; Rodrigues et al., 2016b; Rodrigues et al., 2014; Rogério Tavares Filho et al., 2020; Silva et al., 2018; Velázquez et al., 2020; Wagoner et al., 2018; Zorn et al., 2014) and caloric intake (Meillon et al., 2009, 2010; Missbach et al., 2017; Paglarini et al., 2020). This aspect is highly relevant for accepted and popular foods which induce well defined sensory expectations in familiar consumers. Moreover, the detailed description of the dynamic evolution of sensory properties can be used to highlight the differences among similar products, such as the market leader and competitors, supporting the marketing strategies in the communication of the specific evolution of the sensory profile in time differentiating the target product from its competitors.

Intensity and dominance temporal changes are both relevant for describing the full picture of a product sensory performance (Labbe et al., 2009; Le Révérend et al., 2008; Lorido et al., 2018; Lorido et al., 2016; Morais et al., 2014; Pineau et al., 2009; Rodrigues et al., 2014; Schlich, 2017; Sokolowsky et al., 2015; Sokolowsky & Fischer, 2012). Intensity of dominant attribute can be collected while performing the TDS task and expressed as TDS SCORE that is the average of the intensity score given to an attribute during the evaluation weighted by its duration (Pineau et al., 2009; Labbe et al., 2009). This approach showed product discrimination similar to what is observed with static intensity scoring even if differences were highlighted for complex products with long-lasting sensations (Labbe et al., 2009). This method showed some critical limitations since panelists were asked to switch from a holistic evaluation, needed to select the dominant attribute among all the perceived sensations at a given time, to an analytical mindset, requested to rate the intensity of the selected attribute, thus leading to an increase in task difficulty (Schlich, 2017). An attentional bias on the first dominant attribute that might induce a delay in the selection of the subsequent dominant sensations has been hypothesized to explain differences in TDS curves obtained with or without intensity scoring (Dinnella et al., 2013).

A further methodological issue of dynamic profile sensory description is related to the relative complexity of their graphical representation that makes it difficult to communicate the results to a broader audience than experienced sensory analysts such as R&D company teams and marketing professionals. Alternatives aiming at obtaining clearer representations of the TDS results have been proposed by several authors. A representation of TDS "sensory trajectories" based on principal component analysis was introduced by Lenfant et al. (2009), while Monterymard et al. (2010) proposed a TDS "bandplot" as an alternative to the TDS curves. Furthermore, Pineau & Schlich (2015) added to bandplots a color code to give information about the dominance rates of attributes. Moreover, Galmarini et al. (2017) proposed a "bandplot by descriptor" representation that makes it easier to follow the continuity of a dominant attribute over time. However, the representations of temporal data could still be improved when different sensory measures are combined.

The present study aimed at describing the temporal evolution of the intensity of dominant sensations in alcoholic cocktails prepared with different aperitif liquors (same typology, different brand) considered as a case study of products with subtle sensory differences. With this purpose, results from two largely applied dynamic methodologies, TDS and DTI, were combined. TDS curves of each product were analyzed considering three evaluation intervals (*attack* 0-30 s; *evolution* 31-60 s; *finishing* 61-90 s). Meaningful points for intensity evaluation in DTI were identified from visual inspection of TDS curve intervals. Results from TDS and DTI evaluations were combined in a novel graphical representation describing the perceived differences in intensity of dominant sensations within and between cocktails at the three salient times of evaluation.

2. Materials and methods

2.1 Participants

Thirteen Italian participants (8 women) aged between 25 and 30 years and self-reported cocktail consumers were recruited. Participants had no history of disorders in oral perception and some of them had previously participated in descriptive panels. They received compensation for their participation in the study, but none of them was an "employed" or "professional" assessor. This study was conducted according to the guidelines established in the Declaration of Helsinki. Written informed consent was obtained from all participants in agreement with the Italian ethical requirements on research activities and personal data protection (Law Decree 30.6.03 n. 196) and European regulation on general data protection regulation (EU GDPR n°2016/679).

2.2. Samples

The sample set was composed of three alcoholic cocktails (named: A, B, and C). Cocktail samples were prepared to reproduce the original recipe of the *Spritz* cocktail (https://iba-world.com/new-era-drinks/spritz/). Cocktail samples were composed of three parts of aperitif liquor (11°; 15 ml), two parts of sparkling wine (Prosecco, 11°; 10ml), and one part of soda water (5ml). The three alcoholic cocktail samples were prepared using three different aperitif liquors (same typology, different brand). Each sample consisted of 30 ml of cocktail with a final alcohol content of 8.5°. All ingredients were kept refrigerated (4-8°C) until cocktail preparation. Cocktail ingredients were mixed and two ice cubes of 14 grams each were added to each sample immediately before serving. Each sample was tasted within 10 minutes of the preparation to avoid modification in sensory properties due to dilution (ice melting) or carbonation loss. Widmark's formula (Widmark, 1981) was used to calculate blood alcohol content depending on gender, weight, and age as a function of the total alcohol content of the sample set to ensure that the blood alcohol content of panelists' after each evaluation was always below the drink-drive limit in Italy (0.5 g/l).

2.3. Procedure

The experimental plan consisted of three main steps: 1) TDS evaluations; 2) TDS curve visual inspection and DTI session design 3) DTI evaluations (Fig.1).

2.3.1 TDS Training

Assessors participated in five training sessions consisting of: generation of a list of attributes describing the dominant sensations in alcohol-based cocktail samples (two sessions), panel calibration (two sessions), and TDS evaluation training (one session). In the first session, the concept of dominance was explained to the assessors as "the attribute associated with the sensation catching the attention of the assessors at a given time, not necessarily being the one with the highest intensity" (Bruzzone et al., 2013). For term generation, panelists were asked to taste the three cocktail samples, indicate the dominant sensations, and describe their temporal evolution. After a common discussion, the panel consensus was reached on a list of nine attributes: sweet, sour, bitter, astringent, herbs, rhubarb, spices, citrus, and floral. To facilitate the calibration of the panel on descriptors of dominant sensations, participants were familiarized with basic tastes, astringency, and flavor standard solutions. All the solutions were prepared to induce a moderate intensity of target sensations, corresponding to the central point of the nine-point scale (Table 1).

The last training session was performed to familiarize participants with the software procedure for data recording. The three cocktails were evaluated. Assessors were trained to click on the ''Start'' button as soon as the sample was in their mouth and to immediately start the selection of dominant attributes. They were also told that not all the attributes have necessarily to be selected as dominant and, at the same time, that a given attribute can be selected as dominant several times during the evaluation. After the TDS training session assessors' responses were monitored by visual inspection of the individual graphic outputs in terms of 1) delay (defined as at the time between clicking on "start" button and selection of the first attribute); 2) lack of agreement with the majority of the panel in the selection of dominant attributes during the evaluation. Deviations and incongruences were discussed together with the panel and appropriate corrective procedures were adopted (e.g. additional familiarization or calibration sessions).

2.3.2. TDS evaluation

The temporal evolution of sensations induced by each sample was described using the nine-attribute list. The order of attributes was randomized between participants but was always the same for a given assessor. In total, participants performed four evaluation sessions. Three samples were evaluated in each session. Each sample was replicated four times. Hence, 52 observations (13 assessors∗4 replicates) were collected at each time point for each sample. Samples (30 ml) were presented to participants in 100 ml transparent glasses, coded with random three-digit codes. Samples were presented one by one and the order of the sample presentation was randomized among assessors using a balanced Latin square design. Assessors were asked to hold the sample in their mouth and immediately start the evaluation. After 10 s, assessors were prompted by a screen signal to swallow the samples and to continue the evaluation. The total duration of each evaluation of each sample was 90 s. After tasting a sample, assessors rinsed their mouths with water for 45 s, had some plain crackers for 45 s, and finally rinsed their mouths with water for a further 45 s. All evaluations were performed in individual booths under red lights. Data were recorded every 0.5 s using the FIZZ Software Version 2.40G (Biosystèmes, Couternon, France) and automatically plotted as TDS curves (Dominance Rate – DR vs evaluation time).

2.3.3 DTI session design

The TDS curves of each sample were visually inspected. The dominance patterns of attributes were analyzed considering three main intervals of the dynamic evaluation: *attack* (0-30 s), *evolution* (31-60 s), and *finishing* (61-90 s) (Dinnella et al., 2013; Nguyen et al., 2018; Pineau et al., 2011). For each product, in each interval, only attributes with a dominance rate higher than the chance level were considered. In each evaluation phase, the times at which selected attributes reached the maximum DR value (DRmaxEP) were identified. A specific DTI timing was set up for each cocktail consisting of several intervals, each including the time of DRmaxEP of relevant dominant attributes (Fig. 2). Each DTI session consisted of several "evaluation screens" (ES) reporting: the attributes to be evaluated, the scale for their intensity ratings, and the time available to perform the evaluation task of the relevant ES. Participants could click on the screen to request extra time (of 5 sec each) for completing the task of each ES, if needed. The order of the attribute evaluation in each ES was defined according to DRmaxEP time (from the lowest to the highest) in the relevant time interval. A pause of a few seconds separates the subsequent ESs to ensure that evaluation time of each attribute in each ES exactly superimposes the expected time along the whole evaluation. Figure 3 reports an example of the DTI evaluation procedure. The 9-point scale was used for intensity ratings (1 = extremely weak, 5 = moderate, 9 = extremely strong).

2.3.4 DTI training

The same group of participants that performed the TDS task, participated in two DTI training sessions. In the first session, assessors were calibrated on the 9-point scale for intensity rating using the same standard solutions developed for TDS evaluations. In session two, assessors were familiarized with the procedure for DTI data recording. For this purpose, two samples A and C were evaluated. Participants were asked to put the sample in their mouths, click on the "Start" button, and then start the evaluation. The number of requested extra time was recorded for each subject. The correspondence between expected and recorded evaluation time was checked. Delay in attribute rating and incomplete records were individually discussed and corrected with further individual training sessions. The training was considered satisfactory when all the assessors were able to rate the intensities of attributes of each ES at the expected time. The training was satisfactory for all assessors after two training sessions.

2.3.5. DTI evaluation

Samples were evaluated across four different sessions in four replicates. Sample presentation, rinsing procedure, and data acquisition conditions were the same used for TDS evaluations. Participants were asked to put the sample in their mouths, click on the "Start" button, and then start the evaluation. DTI data were recorded using the FIZZ Software Version 2.40G (Biosystèmes, Couternon, France).

2.3.6 Dynamic spider plot

Data from DTI evaluations were plotted in the dynamic spider plots to summarize the perceived differences in intensity of dominant sensations within a sample along the evaluation time (Within Sample - WS spider plot) or between samples at different evaluation times (Between Sample - BS spider plot). In WS dynamic spider plot each axis corresponds to an attribute. The intensities of the sensation scored during the *attack*, *evolution*, and *finishing* are plotted on the axis. If a given sensation is not dominant at a given phase, this means that the attribute was not scored, and its intensity is set to one by default (extremely weak).

Between samples-BS dynamic spider plot aims at summarizing the information about the dominant sensations common for at least two samples in each evaluation phase tracking the relevant intensity evolution. The BS dynamic spider plot consists of three slices that clockwise represent *attack*, *evolution*, and *finishing*. Axes correspond to the common dominant sensations in each phase; the intensity of the sensations for each sample is plotted on each axis. If a given sensation is not dominant at a given phase for a given sample, this means that the attribute was not scored, and its intensity is set to one by default (extremely weak).

Data analysis

For the TDS data analysis, the binomial distributions were used to identify critical values of the DR at 95% significance (p_s) and chance (p_o) levels. Data were plotted and TDS curves of the alcoholic cocktails were formed using a Bezier smoothing function of the FIZZ sensory software. Attributes with DR higher than p0 can be considered consistent at the panel level (Meillon et al, 2009), thus p0 was fixed as a limit to select dominant attributes to be rated for intensity in DTI tasks.

Sensory trajectory of the three samples was computed according to Lenfant et al., 2009. A covariance PCA on TDS data was performed: the variables are the attributes and the individuals are the three samples at 10 equally spaced time points (i.e., 30 individuals in total). One hundred eighty time points were recorded during the TDS evaluation (one record every 500 ms during 90 s). We reduced the number of time points from 180 to 10 equally spaced in time. The first point (T0A) is the beginning of the TDS evaluation in the *attack* phase then the subsequent nine points represent changes in dominance across all the intervals: Time 1 Attack (T1A) = 10 s; Time 2 Attack (T2A) = 20 s; Time 3 Attack (T3A) = 30 s; Time 1 Evolution (T1E) = 40 s; Time 2 Evolution (T2E) = 50 s; Time 3 Evolution (T3E) = 60 s; Time 1 Finishing (T1F) = 70 s; Time 2 Finishing (T2F) = 80 s; Time 3 Finishing (T3F) = 90 s corresponds to the last score of the *finishing* phase. The observations are the DR values. A PCA biplot was computed to map the samples on the first two principal components of the model. Sensory trajectories are shown on this map by linking the ten points of time corresponding to the same product across the time intervals.

Intensity data from the DTI task were analyzed by multiblock PCA and by one-way ANOVA for each assessor and each attribute combination to assess panel calibration and assessor individual performance, respectively (Næs and others 2010; Tomic et al., 2010). The correlation loading plots for each attribute from the multiblock PCA (Tucker-1 plot) were inspected to identify assessor–attribute combinations deviating from the rest of the panel. Correlation loadings for an assessor interpreting an attribute differently from the rest of the panel are positioned far apart from the rest making it possible to identify assessor–attribute combinations with weak relation to the general underlying data structure. Results from one-way ANOVA models are used to draw p*MSE plots. In these plots, the individual ability of discriminating among samples for each attribute is expressed as *p* value and plotted along the vertical axis, while the consistency over replicates, expressed as ratio of sums of squares of the differences between average values of products and the variance of replicates (MSE), is plotted along the horizontal axis. The lower are both p and MSE values, the better is the assessor performance thus, the presence of weak performers can be detected. Analyses were performed with the software Panel Check (ver 1.4.2, Nofima, Trømso, Norway).

One-Way ANOVA models (time interval as a factor) were employed to test significant differences in intensity within each sample for each attribute across time intervals. Only attributes common for at least two phases of the evaluation were considered. Further One-Way ANOVA models (sample as a factor) were used to detect differences between samples in perceived intensity for each attribute within each interval time (*attack*, *evolution*, and *finishing*) independently. Only attributes common for at least two samples in each interval were considered. Post-hoc Fisher (LSD) multiple comparison tests ($\alpha = 0.05$) were employed to determine significant differences.

Pearson linear correlation test was applied to test the correlation between mean intensity and DRmaxEP for each attribute in all samples (significance level fixed at $p \leq 0.05$). Only attributes dominant in at least two evaluation phases in at least two samples were tested.

Statistical analyses were performed using the XLSTAT software version 2018.1 (Addinsoft, Long Island, NY, USA).

3. Results

3.1. Temporal Dominance of Sensations

Based on the binomial distribution and considering nine attributes and 52 observations (13 assessors×4 replicates), the critical values of the DR for significance of 95% (p_s) and chance (p_o) levels were 18% and 11%, respectively.

The visual comparison between TDS curves highlighted evident differences among cocktails (Fig. 4).

The *attack* phase of samples A and B was dominated by citrus flavor, followed by herbs and to a much lower extent by bitter, sweet, and sour tastes and by rhubarb flavor. In the *attack* phase of sample C, only the dominance of sour taste was similar to the other samples while sweet taste was below chance level and a lower dominance of citrus flavor, as well as a higher dominance of bitter taste, herbs and rhubarb flavors, were observed as compared to the other samples.

In the *evolution* phase of sample A, DR of citrus and herb flavor tended to decrease while bitterness tended to increase. Floral flavor was present above chance level in the *evolution* phase of this sample only. In sample B, DR of citrus tended to decrease, bitterness did not change, and flavor of herbs became the most dominant sensation. In both samples A and B the dominance of sweet taste remained stable as compared to the *attack* phase while sour taste lowered below chance level. The *evolution* phase of Sample C was still dominated by bitter taste and flavor of herbs with the persistence of sour taste and the decrease of rhubarb flavor dominance. Citrus flavor lowered below chance level in this phase.

At the *finishing* phase, the profile of samples A and B was dominated by astringency, sweet taste, and citrus and herbs flavors, while DR of floral was higher than the chance level only in sample A. Bitterness clearly dominated the *finishing* phase of sample C together with astringency, herbs and rhubarb flavor in a much lower extent.

Panel identified "spice" as a dominant attribute during the vocabulary generation but did not reach the consensus on the time at which the attribute dominates the product profile, thus the attribute never reached the chance level and was not taken into account in the DTI task.

3.2. Sensory Trajectories

The first two PCA components accounted for 61.7% of the total variance observed among products (Fig. 5). Sensory trajectories of the products were not parallel in the PCA biplot thus evidencing differences in temporal perception of the samples (Schlich, 2017), however similarities are observed comparing sample A and B while sample C showed a different dominance evolution pattern. Samples A and B trajectories are mainly associated with citrus during the *attack* and with astringency during *finishing*, while they tend to diverge during *evolution* when sample A was mainly associated with floral flavor and sweet taste and sample B with sour taste, herb and rhubarb flavors. Sample C trajectory showed an association with rhubarb, herbs and bitter taste along the whole evaluation time and with astringency during *finishing*.

3.3 Discrete Time-Intensity

Tucker-1 plots showed that correlation loadings were relatively close to each other for the considered attributes. A few subjects deviated in respect to the rest of the panel for a specific attribute at a given evaluation time but no subject-specific systematic lack of agreement with the rest of the panel was found. p*MSE plots indicated that all subjects were reliable in terms of product discrimination ability and consistency across replicates. Thus, panel and subject performance were considered satisfactory and intensity ratings from all subjects were considered in analysis of DTI results. Examples of panelist performance for attributes with significant intensity changes during evaluation intervals are reported as supplementary materials (Fig. 1S).

Significant changes were found comparing the intensity of the dominant attributes rated at the time of their DRmaxEP during *attack*, *evolution* and *finishing* phases in each sample (Table 2).

Sample A and B showed a significant lowering of intensity of bitter and sweet tastes and flavors of citrus and herbs along the evaluation even with slightly different patterns. Sample A showed the same bitterness and sweetness intensity during *attack* and *evolution* while significant lowering of taste intensities was observed at *finishing*; citrus flavor intensity was higher during the *attack* than during *evolution* and *finishing*. Sample B showed a regular significant decreasing of bitter and sweet tastes and of citrus flavor along the evaluation phases. Herb flavor showed intensity higher at the *attack* and *evolution* than at *finishing* in both samples A and B. In sample C, bitterness intensity was higher during *evolution* than during the *attack* and *finishing* phase, flavor of herbs and rhubarb intensity regularly decreased along the evaluation time. Astringency intensity was higher during the *evolution* than during the *finishing* in sample B and C.

Significant differences in intensity were also found comparing the three samples for intensity ratings of the dominant sensations common for at least two samples and in two phases. At the *attack* citrus flavor intensity was lower in sample C as compared to the other samples, while rhubarb flavor was higher in sample C as compared to sample A. During the *evolution* phase sample C showed the highest bitter and astringency intensities, sample A was sweeter than sample B while citrus flavor intensity was higher in sample B than in sample A (these sensations were not dominant in sample C at this time interval thus their intensity scores were not collected for this sample). During the *finishing* phase sample C was the most bitter sample, sample A was higher in citrus flavor as compared to sample B (this sensation was not dominant in sample C at this time interval thus the intensity was not collected for this sample).

For exploratory purposes, the linear correlation between mean intensity ratings and DRmaxEP values was computed only for attributes dominant in at least two evaluation phases in at least two samples. No significant correlations were found for bitterness ($p=0.103$), sweetness ($p=0.704$), citrus ($p=0.920$) and herbs ($p=0.633$).

3.4 Sensory trajectories and intensity data

The comparison of data from DTI evaluation (Tab. 2) and sensory trajectories (Fig. 5) indicate that intensity and dominance tend to evolve with different patterns with few exceptions. For example, both sample A and B show sweetness dominance along the evaluation time, but the intensity of this taste significantly decreases. Bitterness shows a low correlation with the trajectories of sample A and B despite a clear decreasing trend from the *attack* to the *finishing* phase. On the other hand, sensory trajectories of the three samples associate to citrus and herb flavor closer at the *attack* and *evolution* than in the last part of the evaluation, in line with the intensity decreasing of this sensation along the evaluation time. In the same way in sample C rhubarb characterizes the sensory trajectory at the beginning of evaluation when it is perceived at the highest intensity. During the *attack* phase, the sensory trajectory of sample C is much more associated with bitterness and herb flavor than both sample A and B, even if no significant intensity differences among samples were found.

3.5 Dynamic spider plots

WS dynamic spider plot allows to visualize the number and the quality of sensations dominating the profile of a given product and to compare the intensity of a dominant sensation perceived at different times during evaluation. The evolution of intensities of dominant sensations in each sample was depicted in the spider plots reported in Fig. 6. The visual inspection of each plot allows for the easy count of the number of the sensations dominating the profile. This aspect can be considered as a marker of product profile complexity (Meillon et al., 2010). WS dynamic spider plot of sample A (Fig. 6A) showed that four attributes were dominant along the three phases (sweet, bitter, herbs and citrus flavors); two attributes dominate during two evaluation phases (floral flavor and astringency) and two dominate only during one phase (sour taste and rhubarb flavor). Sample B showed a similar attribute dominance pattern; the main difference in respect to sample A was that the floral flavor was not a dominant attribute (Fig.6B). Thus, both samples show a complex sensory profile with several attributes dominating along the evaluation time. On the other hand, the dynamic profile of sample C (Fig. 6 C) appears much simpler with three attributes dominating all the three phases (bitter, herbs and rhubarb); one dominates in *evolution* and *finishing* (astringency) and citrus was dominant only at the *attack*.

The comparison of dominant attributes in WS dynamic spider plot in the different samples also highlights the major differences in dominance across cocktails. Floral flavor represents the characteristic signature of sample A compared to both sample B and C, while the lack of dominance of sweet taste together with the dominance of rhubarb along the whole evaluation time characterize sample C compared to both samples A and B.

Furthermore, mean values and temporal patterns of the perceived intensity of the dominant sensations are tracked in the plot allowing for the quantitative description of attributes dominating the profile in different phases of the evaluation time in each sample. The comparison of WS spider plots graphically shows the peculiarity of the intensity evolution of attributes dominating at least two evaluation phases in each sample, as described in Table 2 by rows. Taste intensity evolution in different samples shows different decreasing pattern: bitterness intensity tends to decrease slower in samples C compared to samples A and B; sweetness decreasing is slower in sample A compared to sample B; intensity of flavor of herbs decreases in a similar way in all samples, while the decline of citrus flavor intensity appears faster in sample A than in samples B.

Between samples-BS dynamic spider plot aims at summarizing the information about the dominant sensations common for at least two samples in each evaluation phase and at tracking their intensity evolution (Fig. 7). BS spider plot shows the similarity among samples in terms of dominant attributes and the continuation of their dominance along the evaluation (i.e., the presence of a sensation in more than one slice of the plot). Bitter and herbs dominated the profile along the whole evaluation time and astringency dominated *evolution* and *finishing* in all samples. Samples shared the dominance of citrus and rhubarb flavors during the *attack* phase. Samples A and B have in common the dominance of sweet and citrus flavor along the whole evaluation time. Data reported in the BS dynamic spider plot graphically depict the evolution of intensity of common dominant attributes as reported in Table 2 by columns and show that when significant differences in intensity of common dominant attributes were found (for example in the case of rhubarb, bitter and astringency), the mean values are higher in sample C than samples A and B with the exception of citrus, lower in sample C in respect to both samples A and B.

4. Discussion

TDS curves show that the most part of attributes in all samples were up the chance and just below the significance levels thus indicating that even if their dominance was not qualified at 95% of significance they were consistently used by the panel (Meillon et al., 2009). Cocktails considered in the present study were prepared with different brands of the same aperitif liquors, thus only subtle sensory differences were expected. Samples with subtle differences and characterized by several sensory properties might lead to TDS curves with several attributes laying in between chance and significance levels since the contextual perception of different attributes might induce the lowering of their DR values (Meillon et al., 2009; Meillon et al., 2010; Tang et al., 2017; Patterson et al., 2021). Thus, chance level was chosen as a less restrictive criterion for selecting dominant attributes to be rated in DTI task with the purpose of tracking even subtle sensory differences among samples.

The fractionation of TDS curves in discrete intervals (*attack*, *evolution*, and *finishing*) was adopted to make the comparison of the evolution of dominance sensations at meaningful times during evaluation easier. The *attack* phase tracks changes in perception while the sample is still in the mouth and immediately after swallowing, *evolution* refers to the perception after swallowing, when the most part of flavor stimuli have reached olfactory receptors due to retro-nasal air flow induced by swallowing, and *finishing* describes aftertaste. This approach enables the retention of the most important information on dominance evolution in food products described by trained panels of assessors (Dinnella et al., 2013; Nguyen et al., 2018; Pineau et al., 2009). Furthermore, the retrospective selection of the key attributes describing the perception at three discrete times during consumption (at first, after a few moments, at the end) by consumers provides product discrimination similar to that from TDS task (Visalli et al., 2020). Food physical changes related to mastication cycles and modifications in the oral environment during food consumption represent the most common criteria to select times for intensity ratings in DTI evaluations (Pionnier et al., 2004; Pedrotti et al., 2019; Kuesten 2018 for review). In the present work, a*ttack*, *evolution*, and *finishing* were selected as meaningful points for tracking the temporal evolution of the intensity of dominant sensations in DTI tasks. In particular, the time at which a dominant attribute reaches its maximum DR in each evaluation phase in each product was used to set up product-specific DTI sessions. Thus, intensity data were collected according to the evolution of the product-specific dominant attributes and it was possible to compare the intensity evolution of dominant attributes common among products in each evaluation phase.

The visual inspection of TDS curves shows that the most part of attributes dominate at some point the cocktail perception of all samples even if with different patterns. The only exceptions were the floral flavor, dominating only in sample A, and sweetness which never reached the chance level in sample C. These observations confirmed the expected similarity of the sensory properties in the three samples since they only differ in the brand of aperitif liquor; one is the market leader and the other two are competitors developed to simulate the leader. Sensory trajectories complement the information from TDS curves and highlight differences and similarities among samples in dominance evolution along the whole evaluation time. The data confirm the appropriateness of TDS methodology for describing a sample set characterized by subtle differences (Meillon et al., 2009, Velazquez 2020) and indicate that sensory trajectory can be a useful approach to describe in mouth sensory changes, not only for solid (Lenfant et al., 2009, Saint-Eve et al., 2015) and semisolid foods (Labbe et al, 2020), but also in the case of beverages.

DTI data indicated that the intensity of dominant taste and flavor descriptors tended to decrease in time with specific trends in each sample. Astringency intensity tended to increase in agreement with the slow onset and long-lasting characteristic of this tactile sensation (Bajec & Pickering, 2008; Green, 1993). Mean values of intensity of taste and flavor attributes are similar in the samples, but their temporal trends are specific for each sample. It is likely to hypothesize that the chemical nature of tastants is different in the three aperitif liquors and this can at least partially account for their sample-specific intensity trends (Higgins & Hayes, 2020). Moreover, interactions across the different sensations induced by each sample might specifically modulate the intensity lowering pattern during tasting. This approach might help product reformulation aimed at the enhancement or suppression of the intensity of target sensations. The sensory profile of new product formulation would benefit from cross-modal interactions that might compensate for changes in concentration of specific tastants (Velázquez et al., 2020).

The variation of dominance did not significantly correlate with intensity changes. Moreover, changes in intensity of dominant attributes in general show a weak association with product sensory trajectories. These results indicate that dominance and intensity cover different aspects of perception. Relying only on changes in perceived intensity for the study of the dynamic of multiple sensations during product tasting could be reductive if the attentional dimension is not considered. In fact, unexpected and uncommon sensations can catch the assessors' attention even when perceived at low intensity levels (Dinnella et al. 2012). This effect could be also observed in the present study; for example, floral flavor represents one of dominant sensations in the dynamic profile of sample A even if perceived at weak intensity (Table 2). On the other hand, considering only the dominance of sensations over time could lead to the underestimation of the impact of a sensory descriptor due to the complexity of the product profile. In particular, when several different sensations catch assessors' attention, for example during the first phase of the evaluation, the dominance selection can be spread across a relatively large number of attributes thus lowering the relevant DR values. The overestimation of a sensation impact might also be possible; for example, in the last part of the evaluation time, only few sensations with long lasting character are likely to be perceived and then selected as dominant. In the *finishing* phase astringency clearly dominates the sample profile even if it is perceived at intensity level from weak to extremely weak. A general, even not significant, pattern of decreasing intensity and increasing dominance during the time-course of the evaluation can be observed for bitter taste in the cocktail samples. This result can be explained considering the complexity of the sensory profile of the tested samples in the first part of the time-course. During the *attack* phase, sample perceptions are not dominated by specific descriptors. As a consequence, the dominance rate for bitter is relatively low even if this sensation has a relatively high intensity. On the contrary, during the *evolution* and the *finishing* phase, the number of dominant attributes tends to decrease leading to an increase of bitterness DR even if its perceived intensity tends to decrease. It is also possible that the assessor's attention is captured by bitter taste all along the evaluation time due to its intrinsic meaning of innately disliked warning-cue (Mennella, 2014). On the other hand, a tendency to both intensity and dominance lowering is observed for flavors present in the cocktail samples. Thus, the DR assigned to the attributes appears a complex response with several aspects playing a role, including the perceived intensity, the attentional capture and the overall complexity of the product sensory profile.

The proposed methodology allows tracking both dominance and intensity by applying two independent dynamic methods in separate sessions. This approach overcomes limitations due to assessor difficulty in changing from holistic to analytic task and attentional bias when the contextual dominance and intensity collection is performed (Schlich 2017; Dinnella 2013).

Charts illustrating the dynamic profile are well suited for a specialist audience but less effective to communicate the results to industry and marketing professionals. To deliver a more easily understandable representation new graphical tools are needed to better summarize the obtained information. Results from the proposed procedure were graphically summarized in a WS and BS dynamic spider-plot to represent the temporal pattern of the intensity of dominant attributes in a given sample and to compare the evolution of dominant attributes and their relative intensity between products, respectively.

Distinctive WS spider plots were obtained for each cocktail highlighting number and kind of sensations dominating the perception and the relevant changes in their perceived intensity. The information carried by dynamic spider plots in terms of number of dominant attributes in different evaluation phases can represent the complexity of the sensory profile along consumption. In fact, the number of perceived sensations, aromas, ingredients, or flavors, represent an index of product perceived complexity (Bitnes et al., 2009; Lévy et al., 2006; Meillon et al., 2010; Paulsen et al., 2015; Porcherot & Issanchou, 1998; Reverdy et al., 2010; Ruijschop et al., 2010; Weijzen et al., 2008), considering a product with few perceived sensations as simpler and a product with many perceived sensations as more complex (Soerensen et al., 2015; Stolzenbach et al., 2016; Sulmont-Rossé et al., 2008). This represents valuable information since complexity is an important factor affecting consumer experience (Palczak et al., 2019;

Pierguidi et al., 2019). Furthermore, given the importance of the temporal dimension in the definition of complexity (Meillon et al., 2010; Patterson et al., 2021; Paulsen et al., 2013; Tang et al., 2016), the dominant sensations from TDS curves summarized in the dynamic spider plots together with their intensity changes could be a valuable tool to further shed light on this aspect of product perception.

BS spider plot summarizes similarity in terms of dominance and differences in terms of intensity among samples thus helping the comparison of sensory performance among products. Dynamic spider plots could also be useful to identify key sensations of a product of interest thus helping product communication strategies based on product distinctive sensory properties. Moreover, the information carried by dynamic spider plots can be combined with consumer hedonic responses thus gaining an insight into temporal drivers of product acceptance.

Limitations in the use of the proposed methodology are represented by the time needed to train assessors to both product description and to dynamic data collection. Data collection with DTI could be particularly challenging because of the simultaneous evaluation of the intensity of several descriptors in a fixed time window. Thus, the number of samples that can be evaluated in each section is limited and a time consuming and attention demanding training of assessors is needed.

5. Conclusions

Results from the present study suggest that the combined use of TDS and DTI has the potential to deliver a detailed description of the dynamic perception of food consumption in terms of both dominance and intensity. avoiding the methodological difficulties in dynamic profile description encountered when the two responses are simultaneously collected.

Dynamic spider plots depict the temporal evolution of sensory perception in a simple and intuitive graphic representation that describes number, quality and intensity of dominant sensation in a single or multi-product representation.

Further research may extend the application of this approach involving a wider range of sensory modalities (i.e. touch) or in different consumption modalities (i.e. multi-bite). Moreover, extending intensity collection to not dominant attributes (e.g. extending the intensity evaluation of an attribute dominant only for one product to all the products) would allow for a deeper understanding of relationships between dominance and intensity.

CREDIT authorship contribution statement

Lapo Pierguidi: Writing - original draft, Conceptualization, Investigation, Formal analysis, Visualization, Methodology. **Sara Spinelli**: Review & editing. **Erminio Monteleone**: Writing - review & editing, Conceptualization, Supervision, Project administration, Funding acquisition. **Caterina Dinnella**: Writing - original draft, Conceptualization, Formal analysis, Methodology.

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CAPTIONS

Fig. 1 Flow chart of the experimental procedure.

Fig.2 DTI evaluation times for each sample (A, B, C), attribute, and evaluation phases (attack, evolution, finishing). Different colors and patterns represent different sensations.

Fig.3 Schematic representation of DTI evaluation procedure for sample A

Fig.4 TDS curves of samples (A, B, C, D). P0 represents the chance level, Ps represents the significance level (95%) vertical lines indicate the three phases of the evaluation (attack, evolution, and finishing)

Fig. 5 Principal component analysis. Biplot representing the sensory trajectories of the three samples. The first point (T0A) is the beginning of the TDS evaluation in the attack phase; then the subsequent nine points (T1-T3) represent changes in dominance every ten seconds across all the intervals: attack (A); evolution (E) and finishing (F).

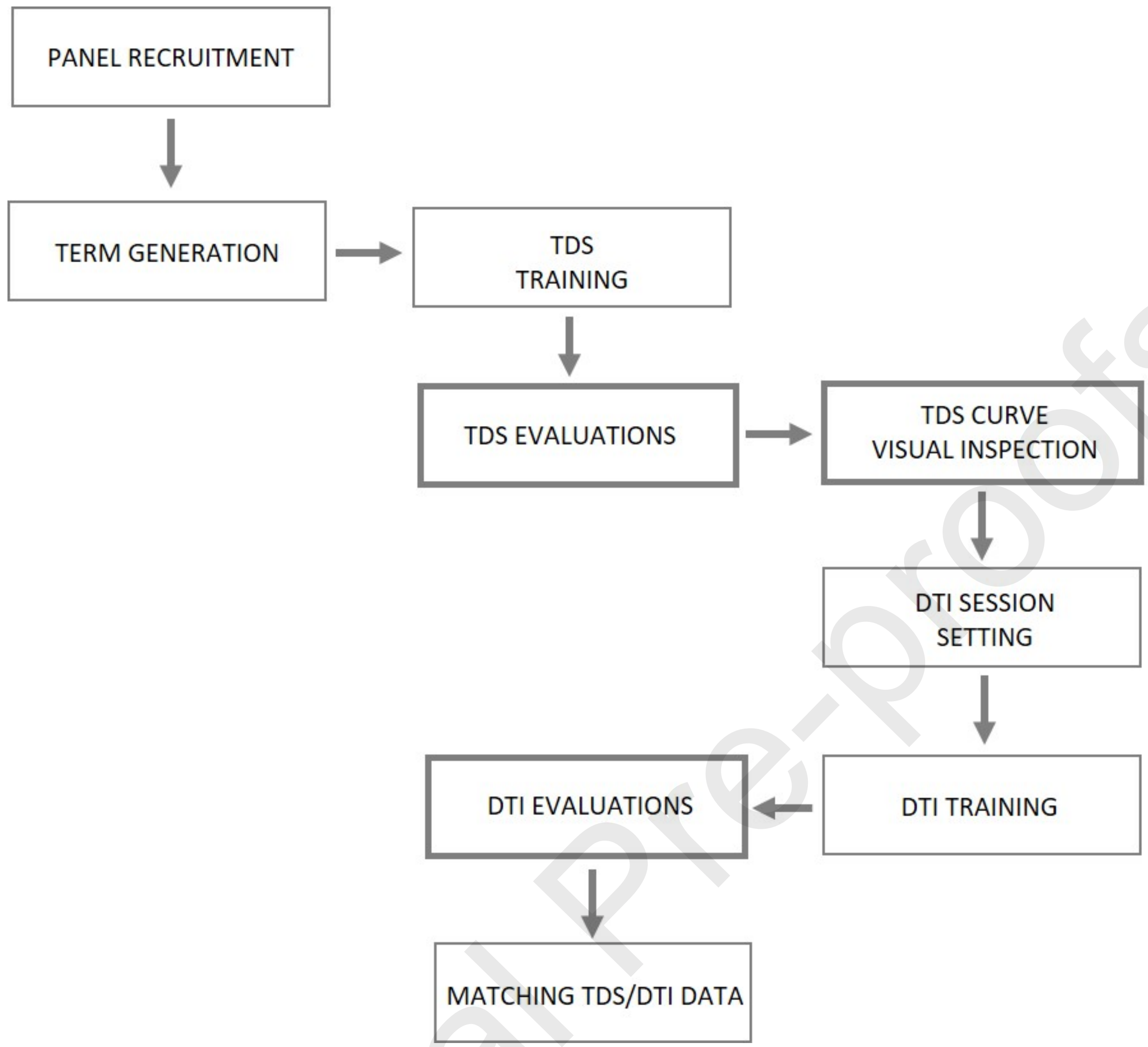
Fig. 6 Within-sample (WS) dynamic spider plot representing dominant sensations and their intensity scores during attack, evolution and finishing in cocktail A, B and C.

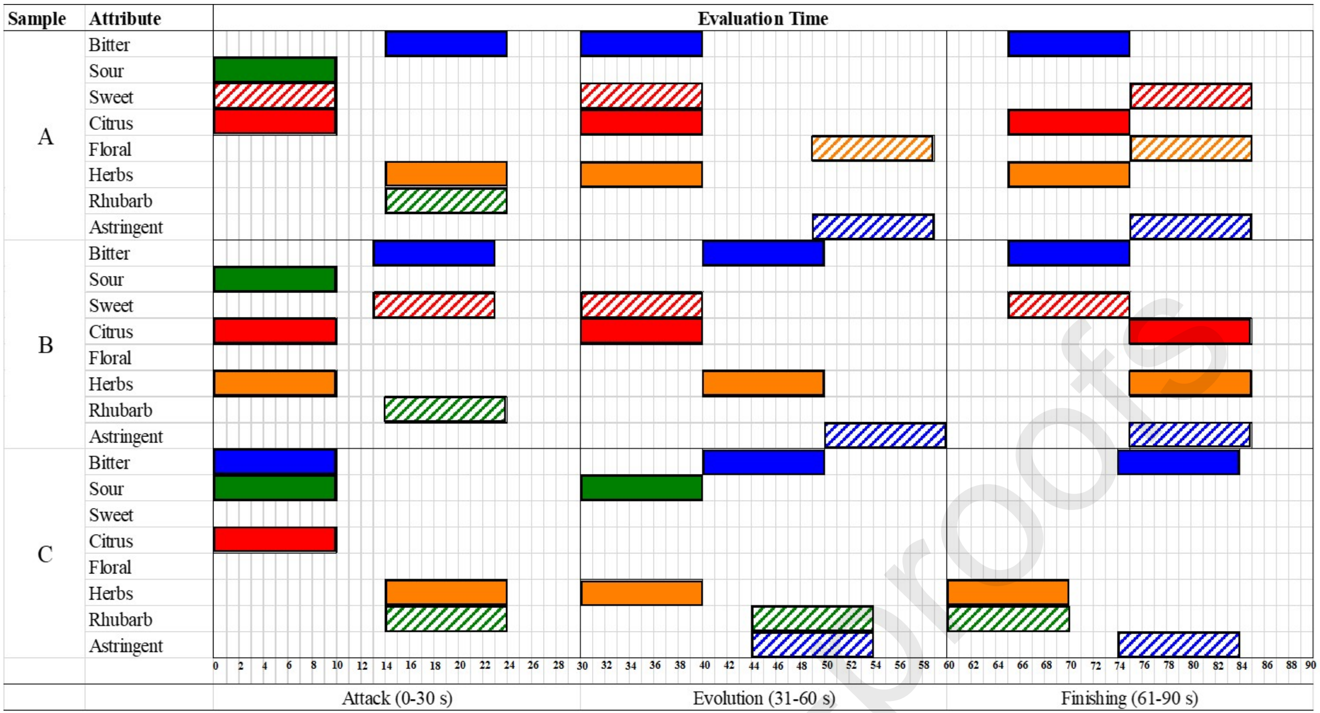
Fig. 7 Between-sample (BS) dynamic spider plot representing dominant sensations and their intensity scores during attack (in green), evolution (in blu) and finishing (in red) in different samples. Only dominant sensations common in at least two samples in each evaluation phase are plotted in the graph.

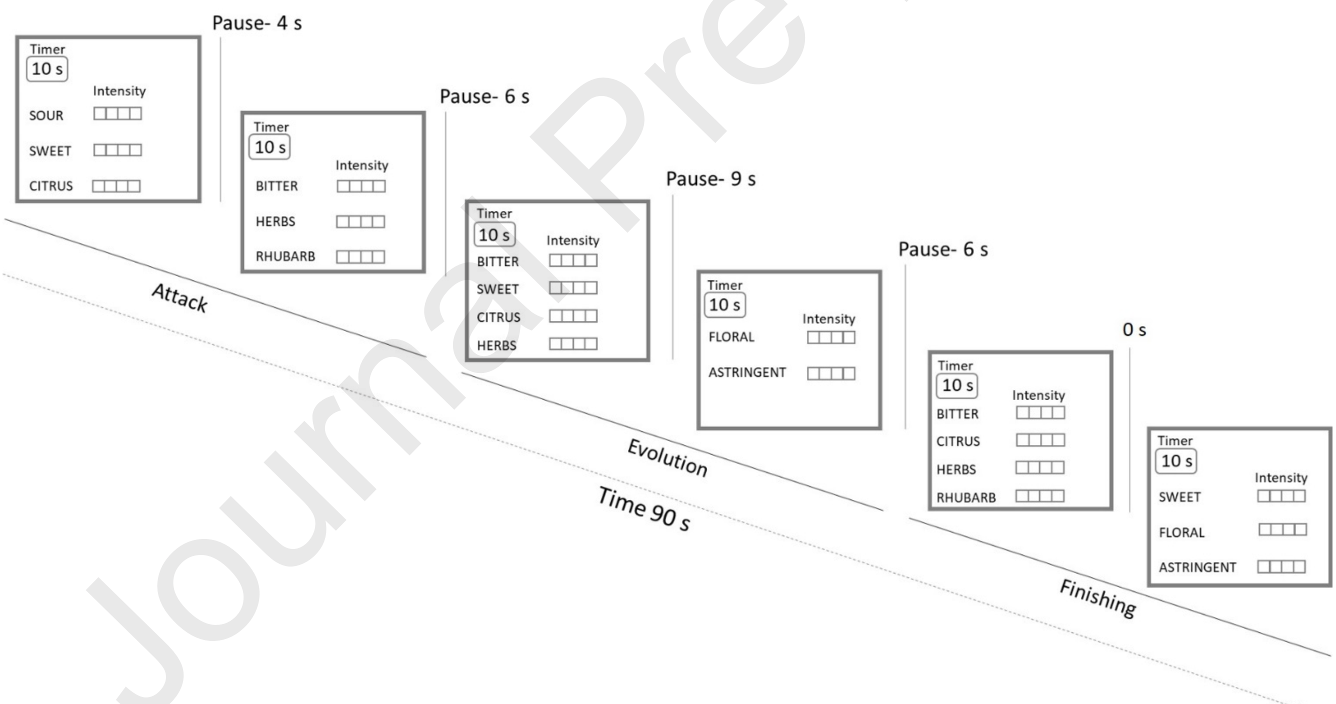
Figure 1S: Assessor's performance for taste and flavor attributes with significant intensity changes during attack, evolution and finishing phases.

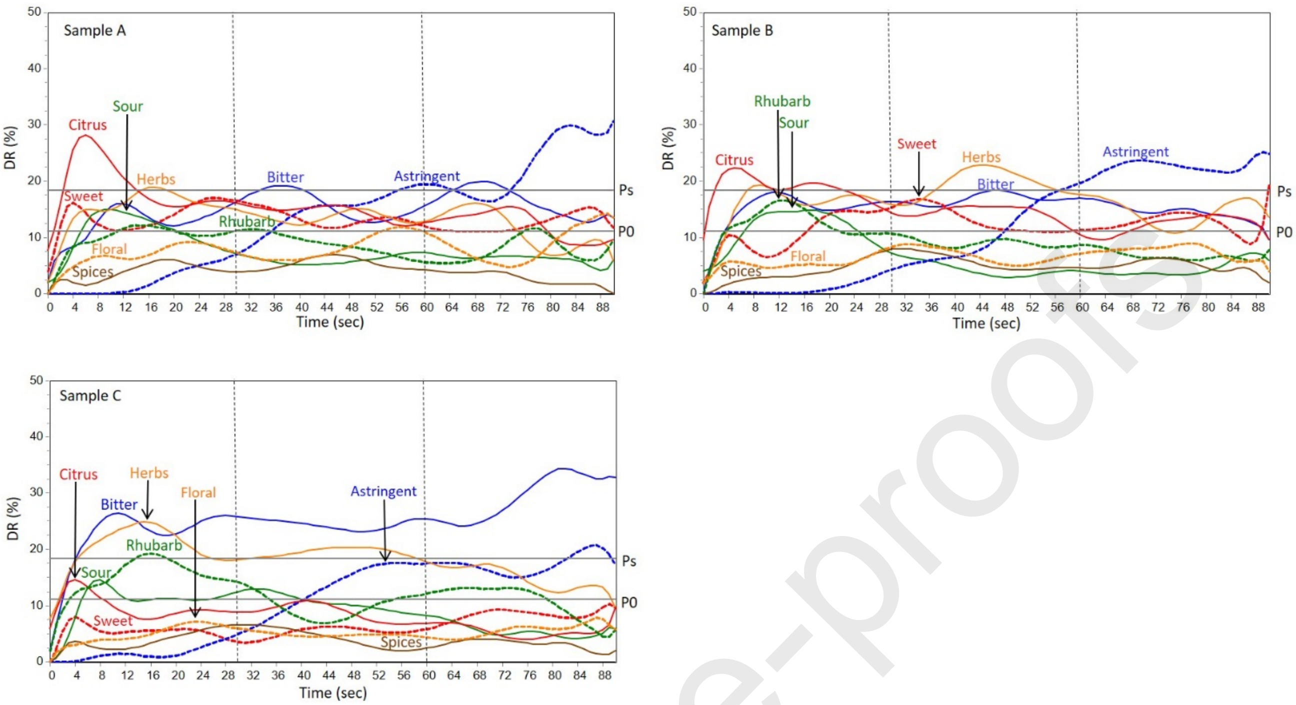
Tucker-1 plots: individual correlation loadings for herb flavor in sample A, bitter taste in sample B and rhubarb flavor in sample C. The external and internal ellipses represent 100% and 50% of explained variance, respectively.

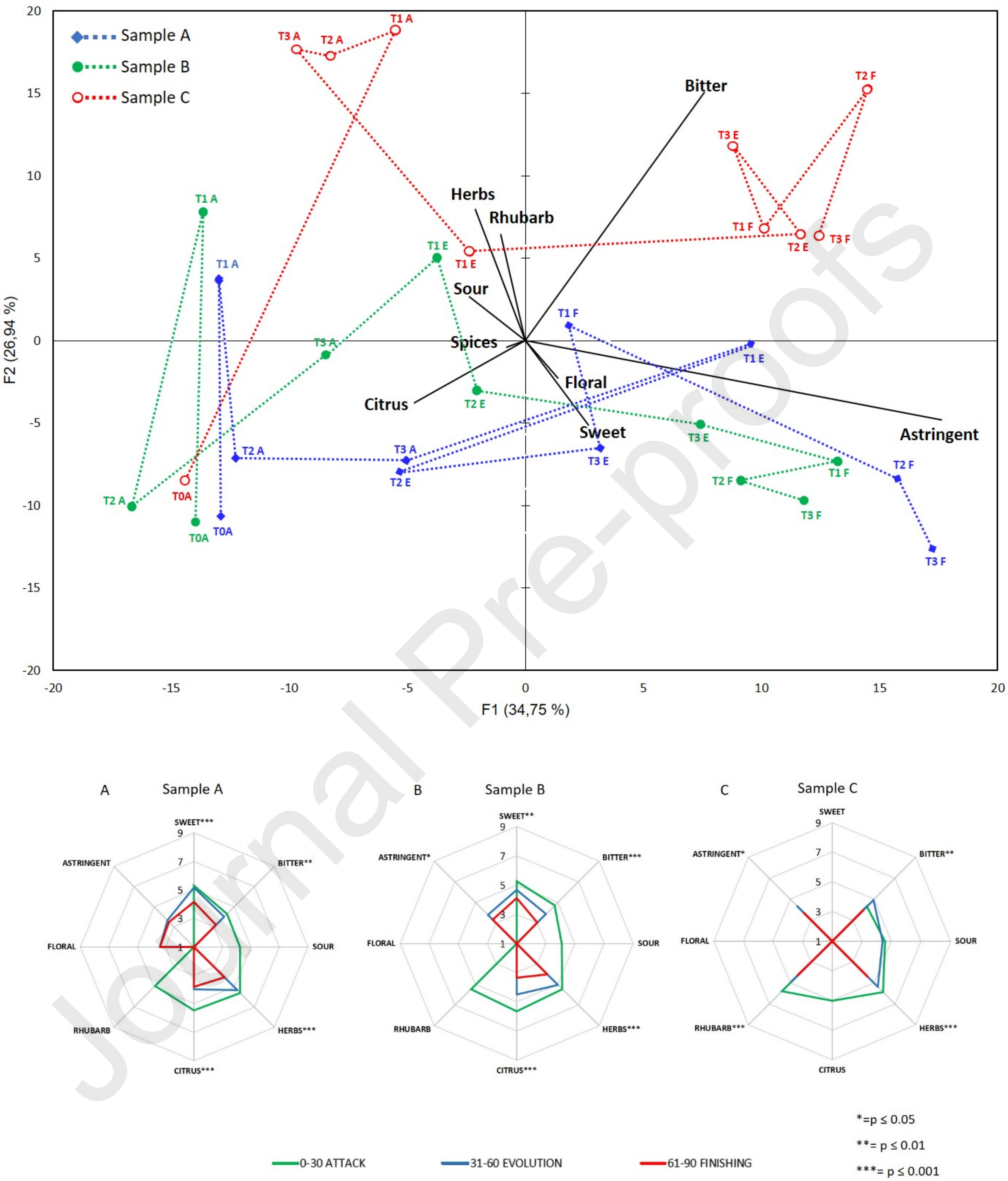
p*MSE plot: assessor individual discriminant and repeatability abilities for herb flavor in sample A, bitter taste in sample B and rhubarb flavor in sample C (assessors are represented by red points).


PANEL RECRUITMENT
TERM GENERATION
TDS TRAINING
TDS EVALUATIONS
TDS CURVE VISUAL INSPECTION
DTI SESSION SETTING
DTI TRAINING
DTI EVALUATIONS
MATCHING TDS/DTI DATA


Sample
Attribute
Evaluation Time
A
B
C
Bitter
Sour
Sweet
Citrus
Floral
Herbs
Rhubarb
Astringent
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90
Attack (0-30 s)
Evolution (31-60 s)
Finishing (61-90 s)


Pause- 4 s
Pause- 6 s
Pause- 9 s
Pause- 6 s
0 s
Timer
10 s
Intensity
SOUR
SWEET
CITRUS
BITTER
HERBS
RHUBARB
FLORAL
ASTRINGENT
Attack
Evolution
Finishing
Time 90 s


Sample A
Citrus
Sour
Herbs
Bitter
Astringent
Sweet
Rhubarb
Floral
Spices
Ps
P0
DR (%)
Time (sec)
Sample B
Rhubarb
Sour
Citrus
Sweet
Herbs
Astringent
Bitter
Floral
Spices
Ps
P0
DR (%)
Time (sec)
Sample C
Citrus
Herbs
Floral
Bitter
Astringent
Rhubarb
Sour
Sweet
Spices
Ps
P0
DR (%)
Time (sec)



Sample A
Sample B
Sample C
F1 (34,75 %)
F2 (26,94 %)
Bitter
Herbs
Rhubarb
Sour
Spices
Citrus
Floral
Sweet
Astringent
T0A
T1 A
T2 A
T3 A
T1 E
T2 E
T3 E
T1 F
T2 F
T3 F
A
Sample A
B
Sample B
C
Sample C
SWEET***
BITTER**
SOUR
HERBS***
CITRUS***
RHUBARB
FLORAL
ASTRINGENT
SWEET**
BITTER***
ASTRINGENT*
SWEET
RHUBARB***
CITRUS
0-30 ATTACK
31-60 EVOLUTION
61-90 FINISHING
*=p ≤ 0.05
**= p ≤ 0.01
***= p ≤ 0.001

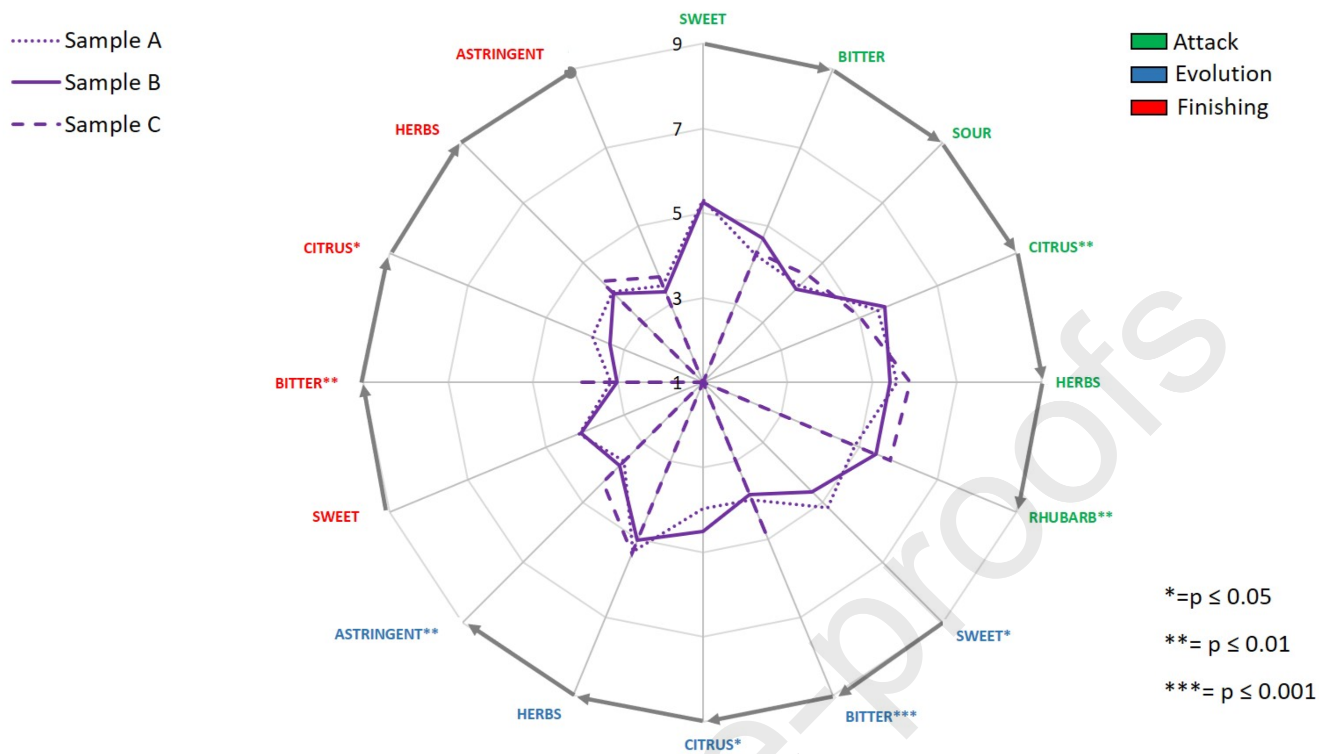


Table 1. Sensory attributes of alcoholic cocktail samples, definitions and standards (moderate intensity on a 9-point category scale).

Attributes	**Definition**	**Standard**
Sweet	Sweet taste	12 g/l sucrose
Bitter	Bitter taste	0.038 g/l quinine
Sour	Sour taste	0.40 g/l citric acid
Astringent	Puckering, drying mouthfeel	0.3 g/l aluminum sulfate
Herbs	Smell of hydro-alcoholic herbal infusions	3% solution (Amaro Montenegro, Montenegro S.r.l)
Citrus	Smell of fresh skin of citrus fruits	0.5 g fresh orange zest
Rhubarb	Smell of rhubarb root infusion	3% solution (dried rhubarb root infusion)
Floral	Smell of orange flowers	6% solution (dried orange flowers infusion)
Spices	Smell of dried spices, such as cloves	1.5% solution (dried cloves infusion)

Table 2. Mean intensity values, standard error and maximum dominance rate in the evaluation phase (DRmaxEP) of attributes in each sample at *attack*, *evolution* and *finishing*. Only dominant attributes common for at least two samples in at least two evaluation phases were analyzed.

Different lowercase letters indicate significant differences within samples (in a row), different capital letters indicate significant differences among samples (in a column) as determined by Fisher's least significant difference (LSD) test.

	Sample	**Measure**	**Attack (0-30 s)**	**Evolution (31-60 s)**	**Finishing (61-90 s)**	**p-value**
Tastes						
Bitter	**A**	DRmaxEP	17.3	25	25	
		Intensity	4.27 ± 0.22^{a}	$4 \pm 0.19^{a\ B}$	$3.17 \pm 0.2^{b\ B}$	**0.0001**
	B	DRmaxEP	23.1	26.9	19.2	
		Intensity	4.7 ± 0.21^{a}	$3.87 \pm 0.18^{b\ B}$	$3.02 \pm 0.17^{c\ B}$	**<0.0001**
	C	DRmaxEP	30.8	30.8	38.5	

		Intensity	4.33± 0.28^{b}	4.94± 0.22$^{a\ A}$	3.98± 0.22$^{b\ A}$	**0.003**
		p-value	0.206	**<0.0001**	**0.0001**	
Sour	**A**	DRmaxEP	17.3	/	/	
		Intensity	4.23± 0.22	/	/	/
	B	DRmaxEP	19.2	/	/	
		Intensity	4.12± 0.27	/	/	/
	C	DRmaxEP	19.2	17.3	/	
		Intensity	4.56± 0.28	4.42± 0.21	/	0.604
		p-value	0.128	/	/	
Sweet	**A**	DRmaxEP	15.4	21.2	17.3	
		Intensity	5.31± 0.28^{a}	5.17± 0.25$^{a\ A}$	4.15± 0.23^{b}	**<0.0001**
	B	DRmaxEP	23.1	21.2	23.1	
		Intensity	5.25± 0.28^{a}	4.65± 0.26$^{b\ B}$	4.12± 0.25^{c}	**0.0001**
	C	DRmaxEP	/	/	/	
		Intensity	/	/	/	/
		p-value	0.823	**0.031**	0.880	
Flavors						
Citrus	**A**	DRmaxEP	32.7	19.2	19.2	
		Intensity	5.46± 0.23$^{a\ A}$	3.98± 0.21$^{b\ B}$	3.83± 0.27$^{b\ A}$	**<0.0001**
	B	DRmaxEP	23.1	19.2	17.3	
		Intensity	5.65± 0.24$^{a\ A}$	4.52± 0.21$^{b\ A}$	3.37± 0.25$^{c\ B}$	**<0.0001**
	C	DRmaxEP	21.2	/	/	
		Intensity	5.02± 0.24^{B}	/	/	/
		p-value	**0.007**	**0.046**	**0.038**	
Floral	**A**	DRmaxEP	/	15.4	15.4	
		Intensity	/	3.4± 0.23	3.4± 0.26	p=1.00
	B	DRmaxEP	/	/	/	
		Intensity	/	/	/	/
	C	DRmaxEP	/	/	/	
		Intensity	/	/	/	/
		p-value	/	/	/	
Herbs	**A**	DRmaxEP	32.7	19.2	23.1	

		Intensity	5.58± 0.19^{a}	5.3± 0.19^{a}	4± 0.24^{b}	**<0.0001**
	B	DRmaxEP	21.2	30.8	17.3	
		Intensity	5.42± 0.24^{a}	5± 0.18^{a}	3.98± 0.23^{b}	**<0.0001**
	C	DRmaxEP	30.8	23.1	21.2	
		Intensity	5.88± 0.22^{a}	5.36± 0.21^{b}	4.39± 0.25^{c}	**<0.0001**
		p-value	0.151	0.232	0.211	
Rhubarb	A	DRmaxEP	15.4	/	/	
		Intensity	4.89± 0.24^{B}	/	/	/
	B	DRmaxEP	19.2	/	/	
		Intensity	5.42± 0.2^{AB}	/	/	/
	C	DRmaxEP	26.9	17.3	13.5	
		Intensity	5.79± 0.27$^{a\ A}$	4.92± 0.22^{b}	4.29± 0.24^{c}	**<0.0001**
		p-value	**0.009**	/	/	
Tactile sensations						
Astringency	A	DRmaxEP	/	23.1	32.7	
		Intensity	/	3.64± 0.22 ^{B}	3.48± 0.25	0.461
	B	DRmaxEP	/	23.1	23.1	
		Intensity	/	3.77± 0.23$^{a\ B}$	3.3± 0.22^{b}	**0.019**
	C	DRmaxEP	/	26.9	21.2	
		Intensity	/	4.33± 0.25$^{a\ A}$	3.7± 0.26^{b}	**0.013**
		p-value	/	**0.003**	0.290	

Highlights:

- A new methodology combining TDS and DTI is proposed
- The time course of dominant attribute intensities was described
- Dynamic spider plots were proposed as a new graphic representation
- The approach might help product optimization and communication strategies