When the choice of the temporal method does make a difference: TCATA, TDS and TDS by modality for characterizing semi-solid foods

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Abstract

For describing the evolution of sensory properties during eating, dynamic sensory methods are still being developed and optimised. Temporal Dominance of Sensations (TDS) and Temporal Check All That Apply (TCATA) are currently the most used and discussed. The aim of this study was to compare TDS, TCATA and a variant of TDS, performed by modality (M-TDS) in the outcome of the dynamic sensory description. These methods were applied with the same trained panel (n = 10) for the evaluation of the dynamic properties of yoghurt samples, with identical composition, only varying in textural properties. Based on a design of experiment, the yoghurts varied in viscosity (thin/thick), size of cereal particle added (flour/flakes) and flavour intensity (low dose/optimised dose, by adding artificial sweetener and vanilla).

The TDS curves revealed that the variation in viscosity and particle size led to differences in perception mainly at the beginning of the eating process (*Thin/Thick* and *Gritty/Sandy*). Additionally, all samples were also perceived as *Bitter* at the end of the eating process. TCATA and TDS by modality results were, generally, in agreement with TDS, but they unveiled more details of the samples' dynamic profiles in all stages of the eating process, showing the effect of *Vanilla* and *Sweet* for the samples with optimised flavour, and the masked perception of *Bitter*.

The duration of the eating process was standardized and split into three time intervals (T0-T40, T41-T80, T81-T100). Panelists' responses were summarized as frequency values in each time interval. Principal Component Analysis was used to visualize sample trajectories over time in the sensory space, with the need to study up to the third dimension to better understand the trajectories. ANOVA models were used to find the attributes which were significantly differences among products. Panel performance was assessed based on MANOVA models for the three methods. The results indicated that TCATA was more discriminative and panelists were more in agreement. TCATA also described samples in more detail in terms of number of discriminating attributes as compared with TDS. The discussion also centers in the different aspects of perception that could respond to different research questions for the three compared methods.

Keywords: *sensory description, TDS, TCATA, temporal methods, dynamic perception, oral processing*

1. Introduction

Eating facilitates two very basic functions for human beings: to gain energy and nutrition and to gain pleasure and enjoyment; understanding sensory perception is essential to explain people's eating behaviour, consumers' acceptance and linking of food products (Chen, 2015; Koc, Vinyard, Essick, & Foegeding, 2013). Processes involved in eating, e.g. mastication and salivation, are dynamic processes (Dijksterhuis & Piggott, 2000). Some models have been proposed to explain the breakdown pathway of food during oral processing that emphasized the dynamic and complex nature of sensory perceptions during the continuous transformation of food from first bite to swallowing (Hutchings & Lillford, 1988; Koc et al., 2013). These researches indicate that sensory perception is a dynamic phenomenon, that is, perception of aroma, taste and texture in foods is dynamic perceptual process with the intensity of attributes changing throughout the steps of oral processing (Cliff & Heymann, 1993).

Descriptive sensory techniques are designed to provide a measure of sensory perceptions based on human assessments relying on methods from neurophysiology and psychology. In sensory analysis, various methods can be used to gain a better understanding of what sensory attributes are responsible for the perceived quality of the products. Classically, sensory methods have focused on static judgements, measuring the averaged intensities of sensations instead of time course of sensations (Di Monaco, Su, Masi, & Cavella, 2014). These methods for sensory profiling do not consider the temporal aspects of sensory perception and may miss crucial information for understanding consumer preferences (Lawless & Heymann, 2010c). This necessitates the study of the methods for measuring dynamics of sensory perception.

Several temporal sensory methods have been developed for dynamic sensory characterization (Cadena, Vidal, Ares, & Varela, 2014). Time Intensity (TI) consists in recording the evolution of the intensity of a given sensory attribute over time. Although the concept of TI was early approached in 1937 (Holway & Hurvich, 1937), this method was used quite extensively since 1970s (Lee & Pangborn, 1986). Nevertheless, TI methodology is performed only on a small number of attributes or with a limited number of products since only one attribute was evaluated at a time (Pineau et al., 2009). In TI, shapes of TI curve are more subject than product dependent (Sudre, Pineau, Loret, & Martin, 2012), leading to individual curves are considered individual “signatures” of assessors; therefore, it is difficult to get the general results for all assessors.

To cover more attributes, TI was extended to the Dual Attribute Time Intensity (Duizer, Bloom, & Findlay, 1997), the Modified Time Intensity (Pionnier et al., 2004) and later on Temporal Dominance of Sensations (TDS). TDS was developed as of 1999 at the “Centre Européen des Sciences du Goût” in the LIRIS lab and first presented at the Pangborn Symposium by (Pineau, Cordelle, & Schlich, 2003). In its inception, TDS was based on Ep Kõster’s idea of a “harmonium of sensations”; he imagined it like a piano “where the panelist could play the melody of the product”, with each piano key as a sensory attribute; this complexity was simplified in TDS to “one key at a time” (Schlich & Pineau, 2017). This method consists in presenting to the assessors a list of attributes, the assessors are then asked to assess which of the attributes is perceived as dominant. During the course of the evaluation, when the assessor consider that the dominant attribute has changed, he or she has to select the new dominant sensation (Labbe, Schlich, Pineau, Gilbert, & Martin, 2009; Pineau et al., 2009). Results from TDS data are described as TDS curves, the dominant rates of attributes (Y-axis) against time (X-axis) for each sample (Cadena et al., 2014). When several attributes have to be compared over time, TDS would be in principle better suited; however, some aspects have been questioned. The first one is the definition of dominant attribute; a dominant attribute is defined as the attribute associated to the sensation catching the attention at a given time (Pineau et al., 2009), whereas other definition shows that dominance is the most intense sensation (Labbe et al., 2009). Apparently, consensus regarding the definition of this concept is lacking between studies (Cadena et al., 2014). In addition, this requirement for sequential selection can potentially result in loss of relevant sensory information, particularly when dealing with complex products that elicit several sensations simultaneously during consumption (Ares et al., 2015). In a recent study, (Varela et al., 2017) explored the conceptualization of “dominance” by trained assessors and consumers. They found that dominance is a complex construct related to multiple aspects of perception, and that different conceptualizations within a panel can influence the interpretation of results. Controversial issues highlighted were around how attributes are selected, the drivers of transitions between attributes, the competition of sensory modalities and how some phenomena like dumping or dithering could happen at some stages in TDS.

TCATA, the temporal extension of Check All That Apply developed in recent years, could potentially overcome some of those issues. In TCATA, the assessors’ task is to indicate and continually update the attributes that apply to the sample moment to moment, that is, one or more applicable sensations are tracked at a given time during mastication (Castura, Antúnez, Giménez, & Ares, 2016). Compared with TDS, TCATA enables the evaluation of more than one attribute at each time, resulting in more detailed description of sensory characteristics of products over time

(Ares et al., 2015). However, the assessors may be so focused on continuously selecting and un-selecting terms that describe a sample that it could result, in some cases, in a more complex or fatiguing method (Ares et al., 2016); this could be particularly the case in a new variant of TCATA, TCATA-Fading, in which the selected attributes become unselected over a predefined duration.

One important drawback of TDS is that dithering and dumping might be enhanced when taste and texture are evaluated in the same task, as fewer terms are available per modality and because panelists need to decide both on the modality and on the attribute (Varela et al., 2017). One possible modification which could overcome this issue, would be running TDS in separate steps, where panelists would be allowed to assess each modality in a different screen, hereby called TDS by modality or M-TDS. This latter method has been proposed by (Agudelo, Varela, & Fiszman, 2015) and applied on fruit fillings and later on cheeses (Bemfeito, Rodrigues, Silva, & Abreu, 2016), but it has not been formally compared to TDS or TCATA from a methodological standpoint.

Until now, some papers have shown that TCATA and TDS provided comparable sample information (Ares et al., 2015), whereas other suggested that TCATA and its variants were able to improve discrimination and deliver a more detailed description (Ares et al., 2017; Ares et al., 2016). The divergence could result from the different products evaluated, or the lack of specific criteria for comparison between the temporal methods.

In this context, the objective of present work was to compare these three temporal methods (TDS, TCATA and M-TDS) based on detailed criteria consisting of dynamic profile, product trajectory and panel performance. The discussion will also center on the different aspects of perception that could respond to different research questions for the three compared methods. This critical comparison will add to the body of literature that can help researchers to select the temporal method best suited to their needs.

2. Materials and methods

2.1. Samples

The idea behind the present research was to start from a design of experiment (DOE) based on the same ingredients, only modifying the product texture by using different processing strategies, so as the samples would have the same calories and composition and these parameters would not influence satiety or satiation, as this methodological study is part of a bigger project looking into satiety perception. The parameters of the DOE were: viscosity (thin/thick), particle size (flake/flour) and flavour intensity (low/optimal). For creating the viscosity differences, two types of yoghurts bases were prepared, one commercial natural yoghurt and another using the same yoghurt in which the texture was modified by stirring for 10 minutes at 25000 rpm in an Ultraturrax PT 3100, irreversible disrupting the gelled structure of the yoghurt and obtaining a thinner, stable version. For the two particle sizes, oat was added in either flakes or flour. Oat flour was obtained by milling the oat flakes with an Ultra Centrifugal Mill ZM200 using a 0.5 mm sieve. Flavour level was varied using two different levels of a combination of acesulfame K and vanilla aroma. “Optimal flavour” intensity was the recommended by the industry providing the yoghurt as the level of sweetener and vanilla they use in commercial low sugar vanilla yoghurt. The “low flavour” level was a perceivable lower level, as per informal tasting by the research team. The optimal intensity was 0.025% acesulfame K and 0.05% vanilla, whereas low level was half of those levels. Finally, eight yoghurt samples were obtained varying in viscosity, particle size of oats and flavour intensity, as per the DOE in Table 1.

The materials used in the preparation of the yoghurt samples were commercial yoghurts (TINE Yoghurt Naturell, TINE, Norway), oat flakes (AXA 4-korn, AXA, Norway), acesulfame K and vanilla supplied by TINE, Norway.

All the sensory evaluations were conducted by Nofima‘s trained panel, in standardized individual booths according to ISO standards (ISO 8589:2007). Samples were served in plastic containers coded with 3-digit random numbers and in a sequential monadic manner following a balanced presentation order. Thirty grams of each yoghurt was served to each assessor for all the evaluations. Two replicates were run for QDA and three replicates for the temporal descriptive tests (TDS, TCATA and M-TDS). Samples were evaluated during normal consumption (no time restriction) and they were spat out after evaluation for the three methods.

2.2. Trained Panel

Nofima’s panel is a highly trained, very stable panel, the 10 assessors are solely hired as tasters, with a part time job, and some of them have more than 20 years’ experience working with descriptive analysis. Panel performance is assessed frequently, and checked for every project. That ensures that all panelists are good enough based on three important qualities: discrimination, repeatability and agreement. The panel has 7 years’ experience with TDS and one year of experience with TCATA.

2.3. Quantitative Descriptive Analysis

Generic quantitative descriptive analysis, inspired in QDA®, was also used in this study as a frame of reference on the static profile of the samples. Sensory profiling was performed on eight samples through generic quantitative descriptive analysis (Lawless & Heymann, 2010a; Stone, Bleibaum, & Thomas, 2012). The descriptive terminology of the products was created in a pre-trial session using samples 4 and 5. These samples were selected in informal tasting by the researchers and panel leader, for showing extremes examples stretching the sensory space. After a 1-h pre-trial session, the descriptors and definitions were agreed upon by the assessors; all assessors were able to discriminate among samples, exhibited repeatability, and reached agreement with other members of the group. The final list (Table 2) was comprised of six odour attributes (*Intensity, Acidic, Vanilla, Stale, Sickening, Oxidized*), three taste attributes (*Sweet, Acidic, Bitter*), six flavour attributes (*Intensity, Sour, Vanilla, Stale, Sickening, Oxidized*) and six texture attributes (*Thick, Full, Gritty, Sandy, Dry, Astringent*).

2.4. Temporal Dominance of Sensations (TDS)

Trained sensory panelists (n = 10) were used for TDS task. The evaluation was conducted following the TDS approach presented by Pineau et al. (2003). Two preliminary sessions were conducted, in which samples were presented in monadic order. In the first, the panelists listed all dominant attributes they perceived while tasting two samples (P4, P5). They discussed these sensations before tasting three next samples (P1, P2 and P8) in the second session. After that, the most frequently cited attributes were selected upon agreement among the panelists. The sensory lexicon generated for the temporal description of the yoghurts included ten attributes (taste/flavour, texture) with their definitions (Table 3).

For the formal assessment, samples were assessed in triplicate. Assessors were asked to put a spoonful of the sample in their mouth and press “START”, subsequently selecting the dominant sensations while eating by clicking at all times one among the ten attributes presented on the computer screen. When the sample was ready to swallow, they pressed “STOP” and spat out the sample. The assessors could successively select as many attributes as they wanted during the oral processing of the samples, including re-selecting an attribute more than once during the test. At all times, only one attribute was selected (the dominant one). Assessors were asked to rinse their mouth with water between samples. Dominance was defined as the sensation that caught assessors’ attention at a given time, not necessarily the most intense.

2.5. Temporal Check All That Apply (TCATA)

The procedure was as described by Castura et at. (2016). Assessors were instructed to review the attributes prior to the evaluation, to get familiar with the attribute distribution on the screen. The TCATA list included ten attributes, the same as in the TDS task. Assessors were asked to check the terms that applied to describe the sensory characteristics of samples at each moment of the evaluation and to uncheck the terms when they were no longer applicable. Unlike TDS, multiple attributes can be selected simultaneously. During the evaluation, the assessors were free to check any unselected attribute, or to uncheck any selected attribute at all times.

2.6. Temporal Dominance of Sensations by modality (M-TDS)

The procedure is similar to the one conducted in TDS task except for the evaluation of flavour and texture modalities in 2 different steps. The list of attributes is the same as describes on Table 3. The assessors tasted one mouthful of a sample and described the dominance of the flavour attributes (*Acidic, Bitter, Cloying, Sweet, Vanilla*) on the first screen. After this, they rinsed their mouths, tasted a second mouthful of the same sample and selected the dominance of the textural attributes during time (*Dry, Gritty, Sandy, Thick, Thin*) on a second screen. The procedure was repeated for the rest of samples.

2.7. Data analysis

2.7.1. Data in sequence of time points

Time standardization was applied to remove assessor noise (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009).

For each point of time, the proportion of runs (subject*replication) for which the given attribute was assessed as dominant was computed. These proportions were smoothed and plotted against time. The curves were called TDS curves. There were two main lines that assisted the interpretation of dominance curves in a plot, ‘‘chance level” and “significant level”. The former represented the theoretical proportion of subjects selecting an attribute at random. Its value, P_0, is equal to 1/p, p being the number of attributes. The latter represented the smallest proportion that can be declared as being significantly higher than the chance level (binomial distribution, α = 0.05). It was calculated using Eq. (1) with n as the number of subject*replication (Pineau et al., 2009).

$$P_s = P_0 + 1.645\sqrt{\frac{P_o(1-P_o)}{n}} \tag{1}$$

For M-TDS, the two modalities – flavour and texture – were recorded on two consecutive screens. For each product and each point in time, the dominant rates by modalities were separately calculated and then plotted together. Since it is possible to obtain two dominant attributes (one for flavour, another for texture) at a given time, the sum of the dominance rates for attributes of each modality, instead of all attributes, was equal to 1.

Basically, TCATA data was arranged in a matrix, with attributes in rows and time slices in columns. An evaluation was the citation proportion of each attribute, calculated as the proportion of judgments (assessors*replicates) for which it was selected for describing a sample at a given time. TCATA curves were showed as smoothed attribute citation proportions over time. For each TCATA attribute, the citation rate of a product of interest can be contrasted with the average citation rate of the other products (Castura, Antúnez, et al., 2016).

Whether TDS or TCATA data, covariance Principle Component Analysis (PCA) was conducted on the table of mean citation proportions (TCATA data) or dominance rates (TDS data) with Product*Times in rows and Attributes in columns. By linking adjacent time points corresponding to the same sample, product trajectories described the evolution in how the sample was characterized over time (Castura, Baker, & Ross, 2016).

2.7.2. Aggregated data in time intervals

Without loss of generality, the evaluation duration in temporal data was split into smaller time intervals (T0-T40: beginning; T41-T80: middle; T81-T100: end) as presented in several researches (Dinnella, Masi, Naes, & Monteleone, 2013; Nguyen, Wahlgren, Almli, & Varela, 2017). For each time interval, only values above the significant level were used and the scores were the average of the scores given to an attribute during an evaluation weighted by their duration (Labbe et al., 2009).

The ANOVA was carried out on the scores, considering sample (fixed effect), replicate (random effect), assessor (random effect) and their interactions as sources of variation (Lea, Næs, & Rødbotten, 1997). In each time interval, only dominant attributes (TDS, M-TDS) or applicable attributes (TCATA) were subjected to the ANOVA model with the purpose of testing the significant differences between respective samples, which had dominant or applicable attributes were detected. The Multiple Factor Analysis (MFA) (Escofier & Pagès, 1994) was applied to the scores. Product spaces and correlation plots were constructed to visualize sample differences and/or similarities in sensory attributes with corresponding time intervals.

The Canonical Variate Analysis (CVA) was conducted based on a multivariate analysis of variance (MANOVA) model with product being a fixed effect, whereas subject as a random one. This is slightly different from standard CVA since it contrasts the between-samples covariance matrix with the interaction covariance matrix (interaction between assessor and samples) instead of the within-group covariance matrix. By doing so, CVA draws the product map based on product means with consideration of subject variability (Peltier, Visalli, & Schlich, 2015b).

To quantify the degree of collinearity in the data, the distribution of Singular Value Decomposition (SVD) was assessed as proposed by Callaghan and colleagues (Callaghan & Chen, 2008). The CVA biplots allowed differences between samples to be visualized while taking account of panelist heterogeneity. Considering k dimensions of sample space, the Hotelling's T-square test was employed to test the hypothesis H0 (the 2 product mean vectors have the same location in the space generated by the first k dimensions). The significant p-value indicated that the mean vectors were statistically different; NDMISIG was the number of dimensions in which the differences between products were significant. Confidence ellipses (90%) have been drawn around each product (Albert, Salvador, Schlich, & Fiszman, 2012; Monrozier & Danzart, 2001; Peltier, Visalli, & Schlich, 2015a; Teillet, Schlich, Urbano, Cordelle, & Guichard, 2010).

The two criteria, namely discrimination ability and agreement, were proposed to assess the panel performance (Lepage et al., 2014; Pineau & Schilch, 2015).

All data were collected with EyeQuestion (Logic8 BV, The Netherlands) and carried out using R version 3.4.1 (R Core Team, 2017).

3. Results

The key point of this research is to focus on the similarities and differences between the temporal methods. Another discussion point will be what research questions can answer each of the methods. For brevity, the details of the specific sensory profiles of each of the samples were not presented here, but they are available on supplementary material to the interested reader. The next three sections will give topline results for the three methods, and Fig. 1 shows exemplar TDS, TCATA and M-TDS curves for two samples P1 and P5 only varying in flavour intensity.

3.1. Dynamic sensory profiling

3.1.1. TDS

The TDS curves showed that texture attributes were the first dominant perceptions for all samples, regardless of the viscosity, particle size or flavour level. For flake-added samples, *Gritty* was dominant at the beginning of the oral processing, coupled with *Thick* or *Thin* depending on the viscosity of the samples. Similarly, *Sandy* was the dominating texture for flour-added samples at the beginning following *Thin* or *Thick*. Those dominances lasted for 30% to 40% of the eating time. The dominance rates were higher than the significance level, but their values were generally low to medium, (0.4 to 0.6), showing that, in general, the attributes did not obtain very high consensus in the TDS evaluation. In the middle of the eating process, *Acidic* was dominant for all samples, and *Bitter* in the middle and end. These perceptions were associated to particle size and flavour intensity. The flour induced a decrease in the dominance of *Acidic* and enhanced *Bitter* dominance regardless of the flavour intensity. In general, samples were less dominantly *Acidic* in optimal level samples. In the last stage of the oral processing, *Bitter* dominant in all samples. It is interesting to note that although *Sweet* and *Vanilla* were selected as important by the panelists to differentiate the samples at attribute selection stage, they were not found as dominant at any moment of the consumption in the TDS test.

3.1.2. TCATA

The temporal profiles of low flavour samples were mainly characterized by texture attributes during all eating process. *Gritty* and *Sandy* were applicable throughout all consumption period. *Dry* was applicable in the second half of the eating period significantly higher than the average for the thin flour samples. This might suggest that the perception of *Dry* was enhanced when viscosity was low, while the thicker texture acted as a lubricant in the tongue against astringent flour particles. The increase in flavour in the optimal level caused an increase in sweet-related sensations considered applicable (*Sweet*, *Vanilla*); in particular, *Sweet* in the beginning and *Vanilla* in the middle of the eating process.

While TCATA highlighted *Sweet* and *Vanilla* flavours as significantly more applicable than the average in the optimal samples, and in some of the low flavour samples, in TDS these two flavours were below the significant line for most samples.

3.1.3. M-TDS

The M-TDS curves indicated that the initial dominant perception was related to the viscosity properties (*Thick/Thin*). The attributes linked to particle size, *Sandy* for the flake samples and *Gritty* for the flour samples, began to be perceived as dominant at 20% of consumption time for all samples, and lasted up to the beginning of the final consumption stage. *Sweet* was selected as dominant attribute for all samples in the beginning of the consumption. Its dominance rate ranged from 0.35 (low flavour samples) to 0.7 (optimal flavour samples) at about 40% of the beginning of the consumption period, meaning than M-TDS highlighted the flavour differences between the samples more than TDS. Importantly, for optimal flavour samples, *Vanilla* was also detected as significantly dominant in this time slot. This was the other apparent difference between TDS and M-TDS curves, as TDS did not highlight *Vanilla* as dominant in any of the samples. At the end of the eating process *Bitter* and/or *Cloying* perception was dominating for all the samples except for sample P8.

More specifically, Fig. 1 shows exemplar TDS, TCATA and M-TDS curves for two samples P1 and P5 only varied in flavour intensity. TCATA curves displayed the proportion of citations for each attribute at each time of the evaluation in which thicker curves show attributes that are more(less) cited than the average at a particular point in time of consumption. For sample P1, the three methods presented similar sensory patterns; the assessors perceived *Thin* and *Gritty* in the first half and then *Acidic* in the second half of the eating process. For the same pattern, M-TDS seems to have discriminated slightly better the sequence *Thin-Gritty*. Nonetheless, the differences among the sensory descriptions between methods appeared when the flavour intensity was increased in the sample (P5). In TDS, perceptions linked to sweet perceptions (*Vanilla, Sweet)* were not dominant, whereas, for TCATA and M-TDS, they perceived *Vanilla* at the beginning and *Sweet* at the middle of the mastication as more applicable or dominant respectively. Note that the assessors even selected *Sweet* as more applicable or dominant at the beginning when they evaluated the low flavour intensity sample (P1). This implies that TCATA and M-TDS seem to be more efficient when unveiling the dynamic flavour characteristics of the samples.

In addition, differences between citation proportions in TCATA and dominance rates in TDS/ M-TDS were observed in all attributes. On average, citation proportions in TCATA were larger than those in TDS, in most cases above 0.8 in TCATA and around 0.4-0.5 for TDS. The forced choice in TDS might explain the lower citation proportion as compared to TCATA. In principle, all the attributes in the list could be cited all along the evaluation in TCATA, but this is not the case for TDS where the probability of citation is always 1/number of attributes. One possible explanation is due to the lack of consensus among assessors on which attributes were dominant. The lower consensus can be due to several concurrent dominant attributes, added to the complexity to the concept of dominance. Consequently, several attributes did not reach significance throughout the evaluation. This complexity could in principle be a valuable result in itself although a difficult one to get direction from.

Regarding method difficulty, in this study, none of the assessors commented about a major complexity or difficulty in the TCATA task. This is in agreement with previous studies on self-reported task perception measures (Ares et al., 2016; Ares et al., 2015). In fact, this particular panel feels more comfortable evaluating temporal perception by TCATA rather than TDS, expressing themselves more freely with TCATA, while in TDS they feel somehow restricted, also explored in Varela et al. (2017).

3.2. Product trajectory

The PCA scores from adjacent time points were joined to give the trajectories, which were presented in Fig. 2. Trajectory plots display the path that follows the sample throughout the sensory space while the sample is consumed (Lenfant et al., 2009), summarizing the evolution of dynamic profile over time. Dimension two accounted for the second largest variability in data, linked to proportions dimension of all attributes, not adding relevant information about the profiles. Thus, dimensions one and three were chosen as the best for displaying differences between samples in the three cases.

The first dimension of the PCA for the three methods was correlated to the attributes *Gritty* on the one side and *Sandy* on the opposite side, separating the samples according to the particle size of the oats. In particular, samples P4, P8, P7, and P3, formulated with oat flour were grouped on one group, whereas the rest (with oat flakes) belonged to the other group.

Meanwhile, the third dimension of the PCA in the three methods was mainly associated with the viscosity attributes (*Thick/Thin*). Samples P2, P6, P4 and P8 were characterized by the *Thick* attribute while samples P1, P5, P3 and P7 by *Thin* attribute.

As mentioned previously, the PCA plots also pointed out evolution of samples over time. The trajectories visualized the common pattern in temporal profile. The products could be split into two groups according to their sensory trajectories: one group with high viscosity (P2, P6, P4 and P8), another group with low viscosity (P1, P5, P3 and P7). The former group was characterized as being *Thick* at the beginning of the eating process, then *Gritty* (samples P2, P6) and *Sandy* (samples P4, P8). The latter group was described by *Thin* at first, turning into *Gritty* and/or *Sandy* at the end of the eating process. In general, flavour attributes did not strongly influence the sample trajectories except for TDS trajectory; *Bitter* was pointed as dominant attribute in the last stage of the eating process for the flour samples (P3, P7, P4 and P8). The attribute partly imparted on temporal sequence of sensations during consumption of samples P4 and P8 in TCATA trajectory.

In general, the evolution pattern was similar among methods. The TDS trajectories, however, was the less resolved. One explanation was possible due to the dithering in selecting a dominant attribute of the panelists, which in turn made the low consensus in their results.

3.3. Product characterization

Regarding QDA results, the 2-way ANOVA indicated that the panelists well discriminated between the samples for all the sensory attributes, except for *Acidic taste* and *Sickening odour*. Two other performance indexes, agreement and repeatability abilities, were also assessed. Nevertheless, the indexes were not the main focus in this study, so they have not been deeply discussed.

To evaluate the sensory profiles provided by each method and to compare them together, a MFA was performed on the combined data composed of TDS, TCATA, QDA, TDS by modalities (flavour, texture) sensory profiles. Each profile was considered as a separate data table in MFA. Within each group, only significant attributes in the three time intervals were selected in the calculations. The MFA analyses were started by examining the canonical correlation coefficients. These coefficients measured the relationship between MFA dimensions and each group of data. Table 4 shows the values of these coefficients, in particular, to TDS, TCATA and QDA groups clearly explained by Dim1, whereas M-TDS by Dim2. The next criterion to evaluate was the RV coefficient (Table 5). As compared with QDA, the RV coefficients of TDS, TCATA and M-TDS were 0.69, 0.83 and 0.39, respectively. This implied a strong link existed between the TCATA and QDA profiles. Graphically, the relationship between the groups and the common space provided by the MFA was evaluated through the partial axes representation (Fig. 3). Without concerning the sign of the correlation, Fig. 3 shows the relationship between MFA dimensions and dimensions of each group (TDS, TCATA and M-TDS). It is worth noting that, the third dimension, instead of the second dimension of M-TDS, linked to the first MFA plane.

The superimposed representation (Fig. 4a) was other important result, indicating how close the different points of view could be, within each product. It suggested that, for any sample, the way how the samples characterized by each method was distinctive. Of those, QDA, TDS and TCATA methods offered similar descriptions, reflecting by the same direction of these methods on the map. Conversely, the standpoint provided by M-TDS was very extreme compared with three methods QDA, TDS and TCATA. It was not surprising as M-TDS was carried out by two sequential modalities, which might be failing to assess the interactions between modalities. Furthermore, the correlation between TCATA and QDA on the map was high, implying that the TCATA description was more highly correlated to the QDA description than to the TDS description.

The perceptual map (Fig. 4b) displays the links between attributes of each method. The results indicated that the same perceptions provided by different methods were highly associated, except for Acidic and Bitter. It is noteworthy that Bitter perception evaluated by TDS and TCATA was not correlated. The *m.Bitter* provided by TDS was mostly explained by the first dimension, the *m.Bitter* provided by TCATA, conversely, taken into account by the second dimension. On the first space (Dim1 vs. Dim2), two perceptions were orthogonal. Regarding Acidic perception, it was perceived differently between TDS and the rest of methods; *m.Acidic* by TDS was not highly correlated to Acidic perceptions of TCATA and M-TDS methods.

To better understand these differences, ANOVA was carried out (Table 6). For each attribute, only the samples dominated and/or applied were compared. All methods showed similar results. The difference was observed between two groups of samples; one group consisting of the samples P1 to P4, another group comprising the samples P5 to P8. The former was formulated with low sweetener intensity while the latter with optimal sweetener intensity. The increase in sweetener intensity resulted in the decrease in perceptions of both *Acidic* and *Bitter*.

3.4. Panel performance

The significant attributes were identified by the ANOVA (Table 7), in which the rows corresponded to the sensory attributes of the data set, the columns to the temporal methods, and each element corresponded to the *p-value* associated with the *F-test* of an effect for a given attribute.

The MANOVA results addressed the multidimensional discrimination, a measure of the separation of the samples in the sensory space generated by the descriptors relatively to panelist disagreement.

The multicollinearities were checked for each of the datasets. As shown in Fig. 5, the values of SVDs did not decrease dramatically, indicating the weak degree of collinearity of datasets. In addition, the sample configurations obtained by CVA also were compared with those of PCA. The comparison indicated that the maps were not too different between CVA and PCA approaches (results not shown). These results were displayed in Fig. 6. The Hotelling's T-square test discriminated all pairs of samples. In TDS biplot (Fig. 6a), two samples P1, P5; three samples P6, P3, P7; and two samples P4, P8 were connected with the other segments, respectively. In TDS map, these segments were located closely to each other as compared with TCATA map (Fig. 6b) and M-TDS map (Fig. 6c). This implied that the sample discrimination in TDS was less effective than in TCATA and M-TDS.

The distribution of panelist scores around the product means could be visualized by confidence ellipses, showing the (dis)agreement between panelists. In TDS, the consensus in selecting dominant attributes was low, resulting in the high variability of the subject scores around the mean. In Fig. 6, the sizes of confidence ellipses in TDS was the largest, whereas those in TCATA and M-TDS were smaller. It is thus possible to confirm the better agreement ability of panelists in TCATA and M-TDS tasks.

4. Discussion

4.1. Comparisons based on product description

Apart from citation proportions and dominance rates, the difference among temporal methods is apparent when comparing the temporal profiles of the optimal flavour samples. The key point is the information related to sweetness; the assessors did not select *Sweet* and *Vanilla* as dominant when tasting samples at any point in the TDS task. The reason can be attributed to the nature of perception. Texture and taste perceptions are more dominant and easier to use and to choose as dominant by panelists to describe products than aroma perception, emphasizing the fact that these attributes are the most discriminating (Kora, Latrille, Souchon, & Martin, 2003; Saint-Eve et al., 2011; Wendin, Solheim, Allmere, & Johansson, 1997). Besides, aroma attributes are perhaps less frequently used than others when a choice has been made from among all of the attributes (Saint-Eve et al., 2011). The panelists, tended to choose mainly textural attributes as dominant when they could choose only one in this example. It is possible to overtake the problem by using alternative procedures such as TCATA or M-TDS. Here, the panelists could select many applicable attributes at a time in the TCATA task, or both texture/flavour as dominant at the same time, because of having them in separate screens in the M-TDS task. As a result, *Sweet* and *Vanilla* appeared as applicable and/or dominant at the beginning and middle of the eating process, respectively.

For TDS tasks, the selection of dominant attributes followed the texture – flavour process. It is somehow logical because the dominant processes are described in hypothetical food-saliva systems, in these sequential steps: comminution – agglomeration – hydration – dilution (Witt & Stokes, 2015). The TDS results showed that texture attributes, were always perceived as dominant at the beginning, and *Bitter* taste dominated at the middle and end of the eating process. Here, it is not certain that sweet related attributes were not selected because they were not dominant (as compared to the rest of the taste/flavour attributes) or if the panelists would always select texture, driven by the natural oral processing sequence. Furthermore, with continuing size of fractured particles reduction, texture perception will become less relevant, and hugely increased surface area helps fast release and diffusion of taste and aroma compounds from food interior. Both phenomena could cause that *Bitter* can be detected as the dominant attribute at the second half of the eating process. In this context, it is also interesting to note, that bitter is an alerting sensation -with the evolutionary object of pinpointing dangers, as poisons- then it could be that cognitively, humans are prepared to detect bitter more dominantly over other tastes or flavours.

Results confirm what Varela et al. (2017) suggested, that in TDS tasks, different modalities are in competition for the “dominance” rating. One could think of some products where texture might be definitely dominant as compared to flavour, highly crispy products for instance, or also some foods where flavour might be much more dominant than texture, espresso coffee for example. Nevertheless, most products would have one flavour and one texture attribute *dominating at the same time*. Flavour and texture are really perceived by different channels, chemesthesis (chemically induced sensations in the oral and nasal cavities) vs somesthesis (tactile and thermal sensations) (Lawless & Heymann, 2010b). So, how is it possible to compare sensations perceived by those two channels and being able to choose only one attribute of one of the modalities? This is a complex decision a panelist needs to do, and that is reflected by the low agreement in TDS tasks, and the high level of noise in the data, due to dithering and dumping effects determined by the difficulty in deciding on the dominant attribute and shifting to the next (Varela et al., 2017).

Food perception is a multisensory phenomenon, reflecting the integration of taste, olfactory, and other sensory information into a perceived property of the food, rather than a collection of individual sensory attributes (Prescott, 2015). In addition, the normal or free oral processing is the most efficient way to judge the sensory attributes of semi-solid foods (de Wijk, Engelen, & Prinz, 2003). These suggest that sensory perceptions should be evaluated simultaneously in order to avoid loss of relevant information. In this context, TCATA seem to reflect better the multisensory experience in food consumption and its relation to the natural oral processing and dynamic sensory perception. Of course, if the objective of the research was to highlight a single dominating sensation, even in the case competing modalities or perceptual channels, TDS will be the method of choice. However, one should be aware that most of the times that would mean that TDS will highlight textural aspects when food physics dominate the consumption phase (beginning and sometimes end of the mastication), irrespectively of how one would change the flavour of the product.

The sample trajectories show the different way how sample characteristics change over time. This observation corroborates that texture properties have a large influence on sensory perceptions of samples. In this study, the viscosity-related attributes were selected at the early stage of eating period, together with particle size attributes. Importantly, *Gritty* and *Sandy* were the most important attributes in the first dimension of PCA biplots, but they are not the first attributes that panelists use to separate samples. In practice, they used *Thick/Thin* as the first classifier. The results support the idea that there seemed to be a privileged time window of expression of some specific sensations in the course of the eating period (Lenfant et al., 2009). According to (Allen Foegeding, Çakır, & Koç, 2010), the sequence of sensation can be grouped based on the different stages of the in-mouth processing of food: prefracture, first bite, chew down and residual after swallowing. Some authors (Chen & Stokes, 2012; de Wijk, Janssen, & Prinz, 2011) found that sensations of those bulk-dominated texture features were detected relatively quickly, whereas sensations of those related to surface properties were detected relatively slowly. That is the important transition of oral sensation of textural properties from rheology to the tribology domain. Consequently, in this case, the attributes related to viscosity (*Thick/Thin*) are perceived first, and then the attributes concerning particle size (*Gritty/Sandy*) were dominating or significantly more applicable later in the consumption. These brings back to the topic that modality or groups of attributes, rather than single attributes could be what drives the dominating sensations throughout the eating process, encompassing the natural oral processing mechanisms, process which TCATA would allow to reflect.

4.2. Comparisons based on panel performance

As testing panel performance, the results were in light with previous research (Ares et al., 2015) that showed TCATA provided a more comprehensive overview of temporal sensations than TDS did. The present study also showed that a modification of TDS (M-TDS) allowing for different modalities to be chosen at the same time, could overcome the above discussed issues that make TDS less efficient. Evidence of better discrimination of TCATA and M-TDS supports the idea that only one dominant attribute chosen at a given time leads to missing relevant information of the sensory characteristics of food products. In addition, panelists show a good agreement for describing the samples. This indicates that TCATA is not a complex and fatiguing method for panelists and can be used to obtain a reliable description of the dynamics of sensory perception.

4.3. Which method for which research question

The methods compared in this work are based on different conceptual aspects (applicability vs dominance), and there is still a lot of research and thinking to do, particularly in terms of which methods answer to which research questions. The results of the present study suggest that TCATA task could be recommended to capture in a more natural way the dynamic and multisensory perceptions of food products, where assessors could freely choose the number of sensations relevant at each moment. M-TDS on the other hand, also seems to retrieve the multisensory aspects of the dynamics of perception, and could be recommended when one is interested in dominance, or how one sensation could overshadow others in a product at different points in time, without losing sight of product complexity. TDS however, generates a more restricted outcome, less discrimination between products, and the biases because of attribute restriction could be limiting at the time of interpreting results (see Varela et al. (2017) for an in depth discussion of the dumping and dithering effects in TDS evaluation). Some researchers suggest the TDS could be better suited to consumers than to trained panelists (Schlich, 2017; Varela et al., 2017), however, the majority of the research done so far in TDS has been with trained panels (Schlich, 2017); so more research is definitely needed to see what aspects of consumer perception TDS can reflect. In this sense, it will be interesting to better understand how much are temporal dominant attributes in a product relevant for preferences, food reward, food intake, etc. Some authors (Thomas, Visalli, Cordelle, & Schlich, 2015) suggested TDL (temporal drivers of liking) as a tool for looking into temporal liking; other authors (Delarue & Blumenthal, 2015) have presented some research also in their review on temporal aspects of consumer preferences, but not much research has been done in this area. The main question would be, how is temporality of sensory perception linked to product appreciation and intake? And which is it the best method for looking into it?

Another point worth discussing is the difference in evaluation processes, from perceptual and cognitive points of view; in principle, applicability as measured by TCATA, seems to be quite different than evaluating dominance, as in TDS or M-TDS, i.e. “tick all what is there” as compared to select “the one” dominant attribute. However, the present results suggest that M-TDS is somehow closer to TCATA than to TDS, even if it relies in dominance evaluation. Then, one could think that applicability and a less restricted dominance are not that far in approach. Particularly thinking that the applicable attributes in TCATA need to be chosen in a very fast sequence, one could think that the “most applicable attributes” would in a way be also the “most striking”, generating a less restrictive selection of a higher number of “dominant” attributes. This point would definitely be worth further studying in future research.

5. Conclusions

This paper presents a reasonable and meaningful basis for monitoring and comparing performances of three temporal methods (TDS, TCATA and M-TDS). The multiple selection of attributes (totally in TCATA or partly in M-TDS) at a given time provides a better dynamic sensory characterization. TDS provides a meaningful description of the attributes if for some reason one is interested in one attribute only to be selected at a time. M-TDS however, still looks into dominance as a concept, but allows for different modalities to be represented, obtaining a richer description, but also more robust results than TDS. TCATA would bring even additional information where interaction between attributes is required and allows to represent more than two attributes at any point in time.

In the current research, TDS was performed according to the definition of dominance attribute proposed by (Pineau et al., 2009). However, a general consensus has not been reached among researchers regarding the concept of dominance and thereby it should be further discussed in future studies. One limitation of this study is the fixed order in which methods were carried out, that is, TDS, TCATA and then M-TDS, next studies could include a randomised allocation to method to the different panelists.

Future research should go deeper in methodological comparisons of TDS, M-TDS and TCATA, to better understand what specific questions could be answered by the different methods, and what are their advantages and limitations for specific product categories. This could include comparison between different panels with the same training, as well as using consumers instead of trained panelists systematically to being able to further conclude on recommendations for application.

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Table 1. Formulation of the yoghurt samples.

Sample	Viscosity	Particle size	Flavour intensity
P1 (t-F-l)	Thin	Flakes	Low
P2 (T-F-l)	Thick	Flakes	Low
P3 (t-f-l)	Thin	Flour	Low
P4 (T-f-l)	Thick	Flour	Low
P5 (t-F-o)	Thin	Flakes	Optimal
P6 (T-F-o)	Thick	Flakes	Optimal
P7 (t-f-o)	Thin	Flour	Optimal
P8 (T-f-o)	Thick	Flour	Optimal

Table 2. Sensory attributes for QDA task.

Attribute	Abbreviation of attribute	Definition
Intensity odour	Intensity_o	Total intensity of all odours in the product
Acidic odour	Acidic_o	Relates to a fresh, balanced odour generally due to the presence of organic acids
Vanilla odour	Vanilla_o	Relates to a vanilla odour
Stale odour	Stale_o	Relates to a stale odour (as in cloying, barn, refrigerator etc.)
Sickening odour	Sickening_o	Relates to a sickening odour (as in cloying)
Oxidized odour	Oxidized_o	Relates to an odour caused by oxidization (cardboard)
Intensity flavour	Intensity_f	Total intensity of all tastes and flavours in the product
Sour flavour	Sour_f	Relates to a fresh, balanced flavour generally due to the presence of organic acids
Sweet taste	Sweet_t	Relates to the basic taste sweet (sucrose)
Acidic taste	Acidic_t	Relates to the basic taste acid (citric acid)
Bitter taste	Bitter_t	Relates to the basic taste acid (caffeine)
Vanilla flavour	Vanilla_f	Relates to a vanilla flavor
Stale flavour	Stale_f	Relates to a stale flavour (as in cloying, barn, refrigerator etc.)
Sickening flavour	Sickening_f	Relates to a sickening flavour (as in cloying)
Oxidized flavour	Oxidized_f	Relates to a flavour caused by oxidization (cardboard)
Thick	Thick	Mechanical textural attribute relating to resistance to flow. It corresponds to the force required to draw a liquid from a spoon over the tongue
Full	Full	Mechanical textural attribute relating to resistance to flow. A rich sensation of the product in the mouth
Gritty	Gritty	Geometrical textural attribute relating to the perception of the size and shape of particles in a product
Sandy	Sandy	A sandy sensation of a sample in the mouth
Dry	Dry	Relates to a feeling of dryness in the mouth
Astringent	Astringent	Describes the complex sensation, accompanied by shrinking, drawing or puckering of the skin or mucosal surface in the mouth

Table 3. Sensory attributes for the yoghurts in the three temporal tasks.

Term	Definition
Acidic	Relates to the basic taste acid (citric acid)
Bitter	Relates to the basic taste acid (caffeine)
Cloying	Relates to a cloying flavour (stale, sickening, flavourless)
Dry	Relates to a feeling of dryness in the mouth
Gritty	Geometrical textural attribute relating to the perception of the size and shape of particles in a product
Sandy	A sandy sensation of a sample in the mouth
Sweet	Relates to the basic taste sweet (sucrose)
Thick	Mechanical textural attribute relating to resistance to flow. It corresponds to the force required to draw a liquid from a spoon over the tongue (High intensity = viscous - thick)
Thin	Mechanical textural attribute relating to resistance to flow. It corresponds to the force required to draw a liquid from a spoon over the tongue (No intensity = fluid - thin)
Vanilla	Relates to a vanilla flavour

Table 4. Canonical correlation coefficients from MFA

Group	Dim1	Dim2	Dim3
TDS	0.97	0.90	0.75
TCATA	0.98	0.96	0.78
QDA	0.94	0.85	0.61
M-TDS	0.82	0.97	0.94

Table 5. RV coefficients from MFA

	TDS	TCATA	QDA	M-TDS
TDS	-	-	-	-
TCATA	0.79	-	-	-
QDA	0.69	0.83	-	-
M-TDS	0.53	0.55	0.39	-

Table 6. p-values from Tukey's HSD test for the two attributes *Acidic, Bitter*.

	b.Acidic			m.Acidic		m.Bittter	
	TDS	TCATA	M-TDS	TDS	M-TDS	TDS	TCATA
P1	0.07^{ab}	-	0.23^{a}	0.33^{a}	0.40^{ab}	0.17^{b}	-
P2	0.19^{a}	0.22^{ab}	0.23^{a}	0.35^{a}	0.46^{a}	0.19^{ab}	-
P3	0.12^{ab}	0.27^{a}	0.25^{a}	0.20^{ab}	0.28^{abcd}	0.33^{ab}	-
P4	0.10^{ab}	-	0.24^{a}	0.17^{ab}	0.31^{abc}	0.32^{ab}	-
P5	0.64^{b}	0.09^{b}	0.05^{b}	0.26^{ab}	0.25^{abcd}	0.11^{b}	0.31^{b}
P6	0.07^{b}	-	0.03^{b}	0.23^{ab}	0.20^{bcd}	0.21^{ab}	-
P7	0.09^{ab}	-	0.02^{b}	0.10^{b}	0.07^{d}	0.34^{ab}	0.62^{a}
P8	0.53^{b}	-	0.05^{b}	0.09^{b}	0.10^{cd}	0.42^{a}	-

Different letters in the same column indicate statistical differences ($p < 0.05$) among the products.
b., m. was the notation of beginning, middle time intervals.

Table 7. Significant attributes resulting from ANOVA (p-value).

	TDS	TCATA	M-TDS
b.Acidic	0.093	0.100	<0.001
b.Gritty	-	<0.001	-
b.Sweet	-	0.006	0.007
b.Thick	0.051	-	<0.001
b.Thin	-	-	<0.001
b.Vanilla	-	-	0.022
m.Acidic	0.029	-	0.020
m.Bitter	-	0.074	-
m.Cloying	-	-	0.023
m.Dry	-	-	0.001
m.Gritty	-	<0.001	-
m.Sandy	-	<0.001	-
m.Sweet	-	0.086	0.013
m.Thin	-	0.086	0.007
m.Vanilla	-	-	0.011
e.Bitter	0.021	-	-
e.Cloying	-	-	0.007
e.Sandy	-	<0.001	-

b., m. and *e.* were the notation of beginning, middle and end time intervals.

Figure Captions

Fig. 1. Temporal curves by sample P1 (left) and sample P5 (right) evaluated by TDS (a), TCATA (b) and M-TDS (c).

Fig. 2. Smoothed trajectories resulting from PCA on dimensions 1, 3. The sample labels were positioned at the end of the trajectories.

Fig. 3. Partial axes plot resulting from the MFA performed in combined data composed of QDA, TCATA, TDS and TDS by modalities.

Fig. 4. The superimposed representation and perceptual map from the MFA performed in combined data composed of QDA, TCATA, TDS and TDS by modalities. b: beginning; m: middle, e: end of the eating process.

Fig. 5. The distributions of SVD for sample covariance matrix (*top*) and interaction covariance matrix (*bottom*) in TDS (a), TCATA (b) and M-TDS (c).

Fig. 6. The CVA biplots for TDS, TCATA and M-TDS methods.

Figure 1
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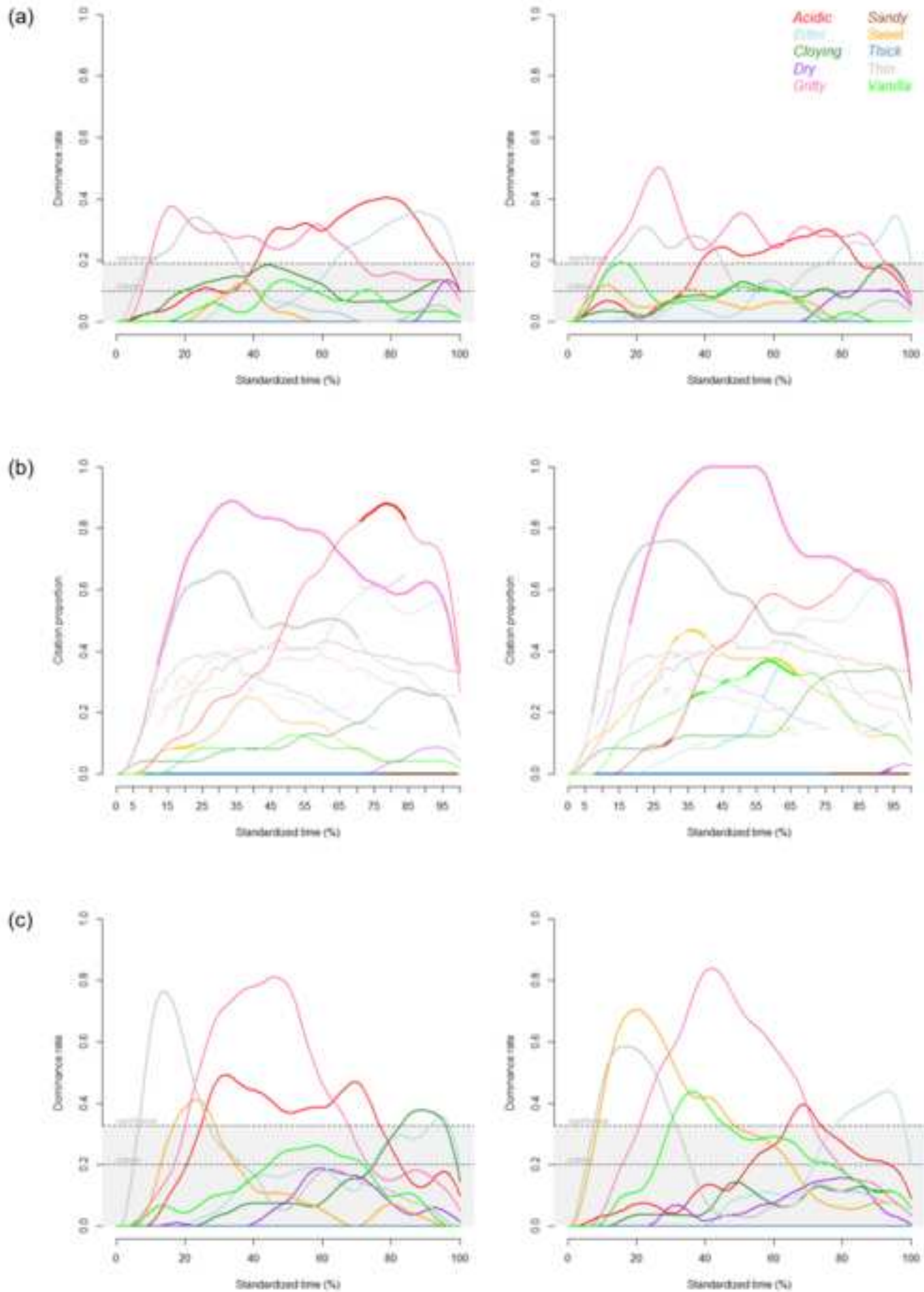

Figure 2a
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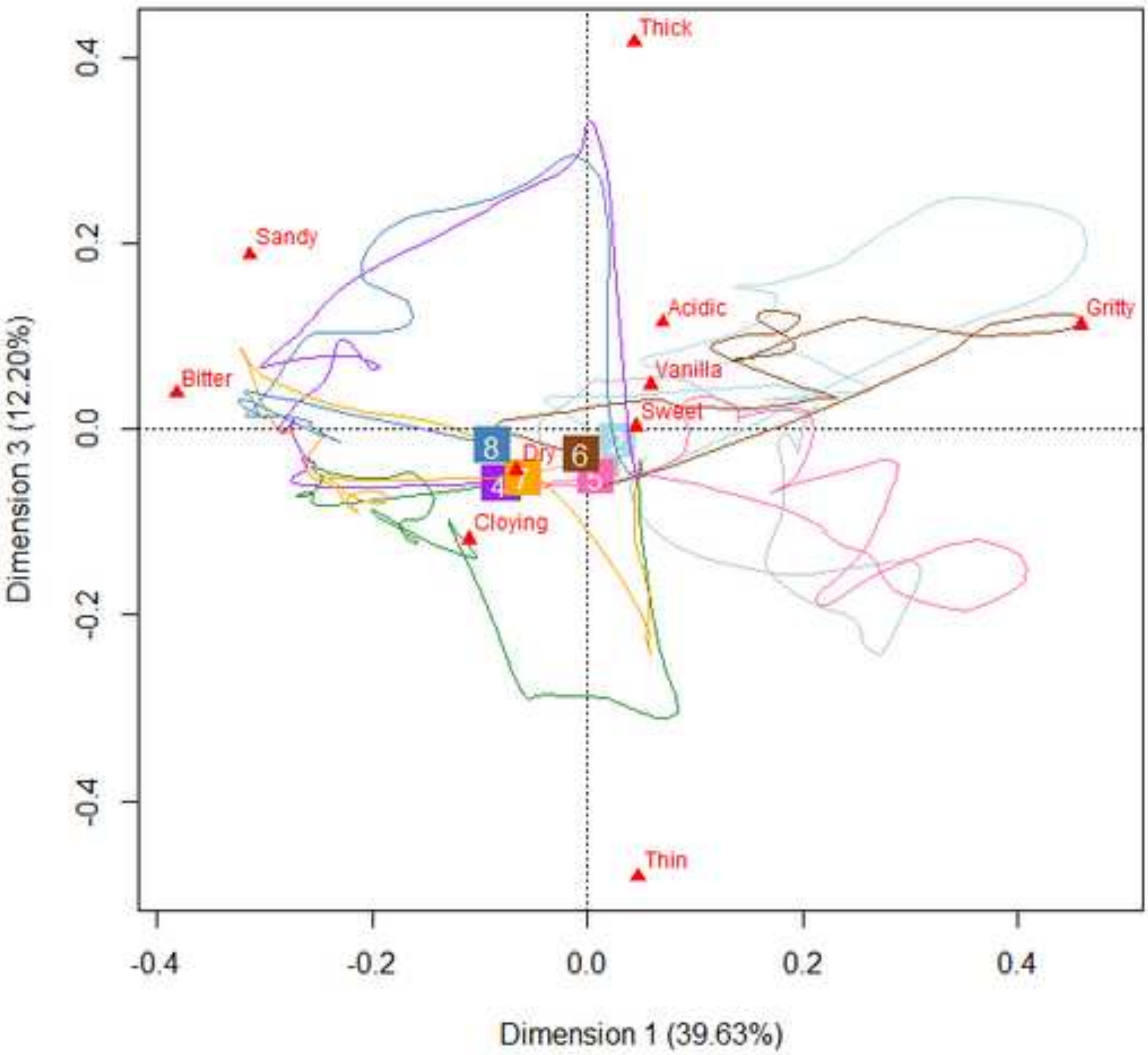

Figure 2b
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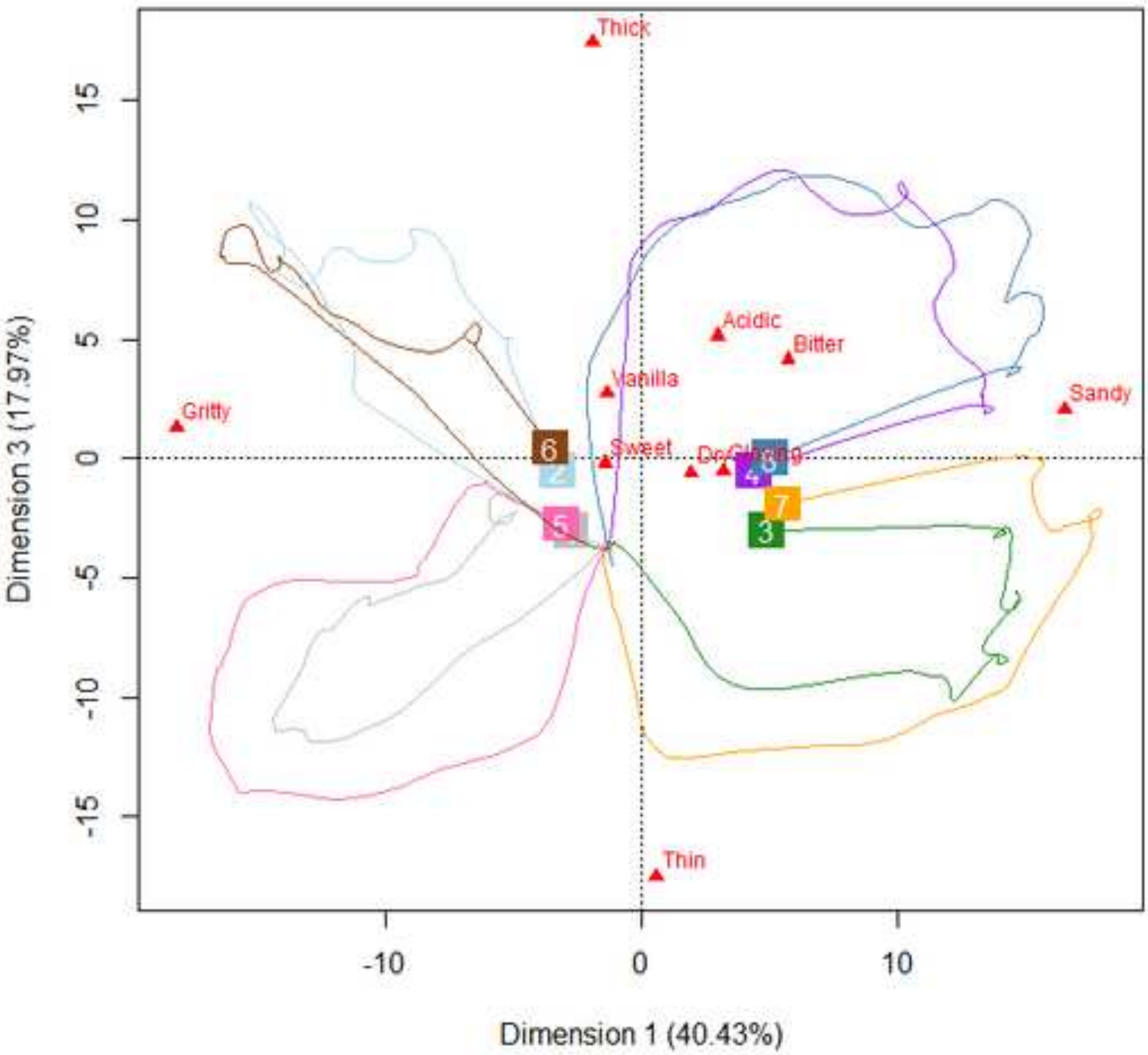

Figure 2c

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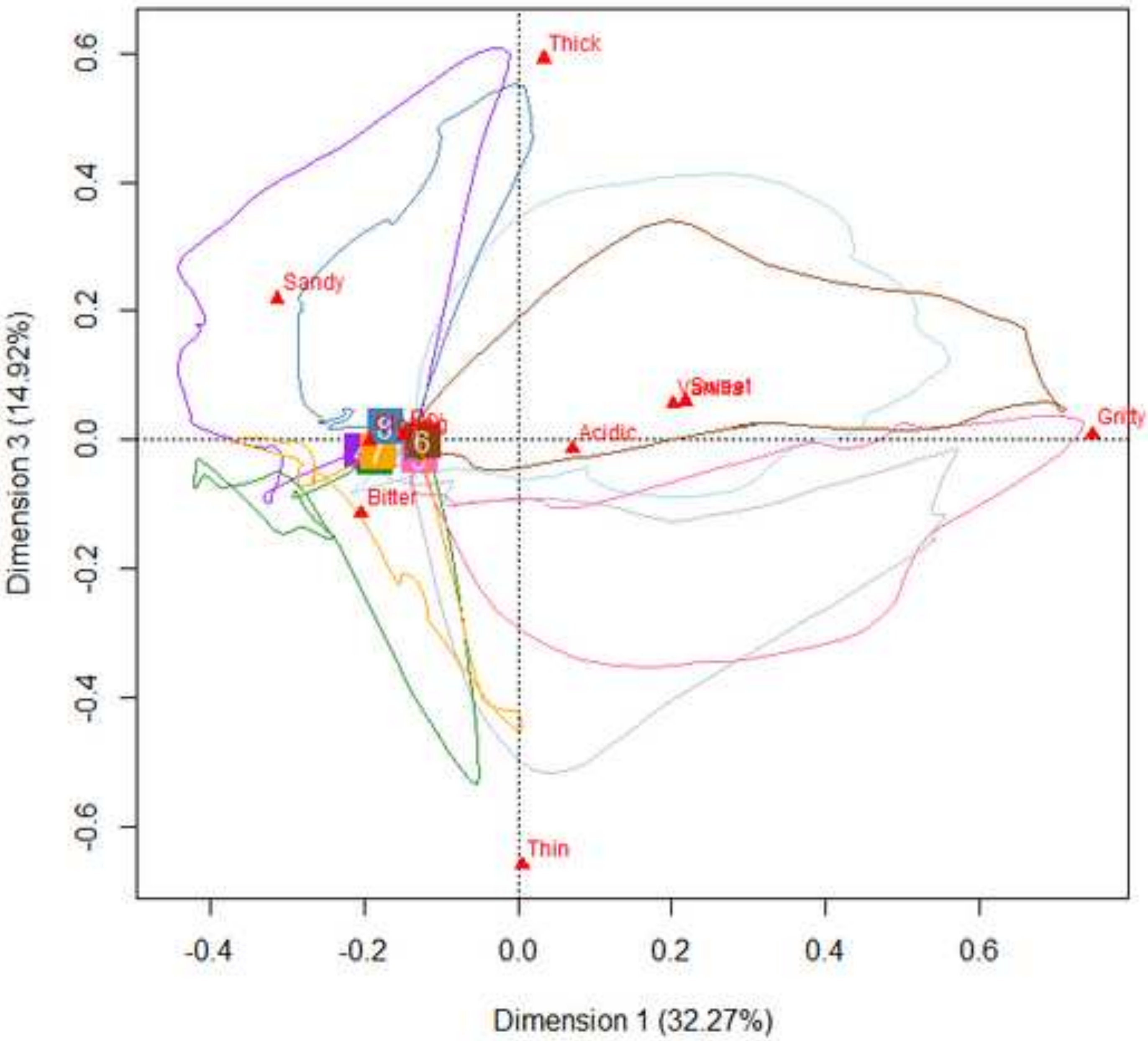

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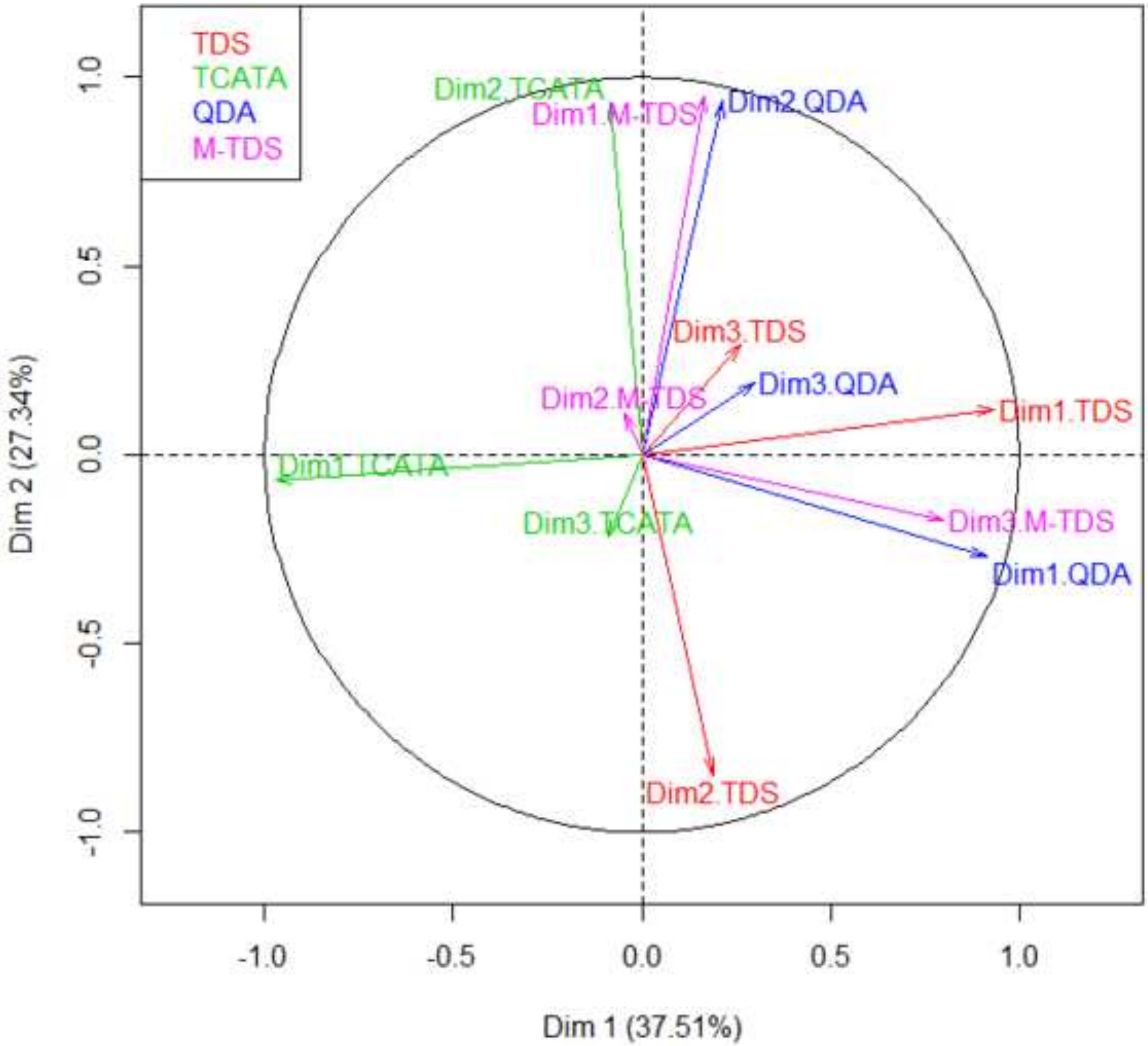

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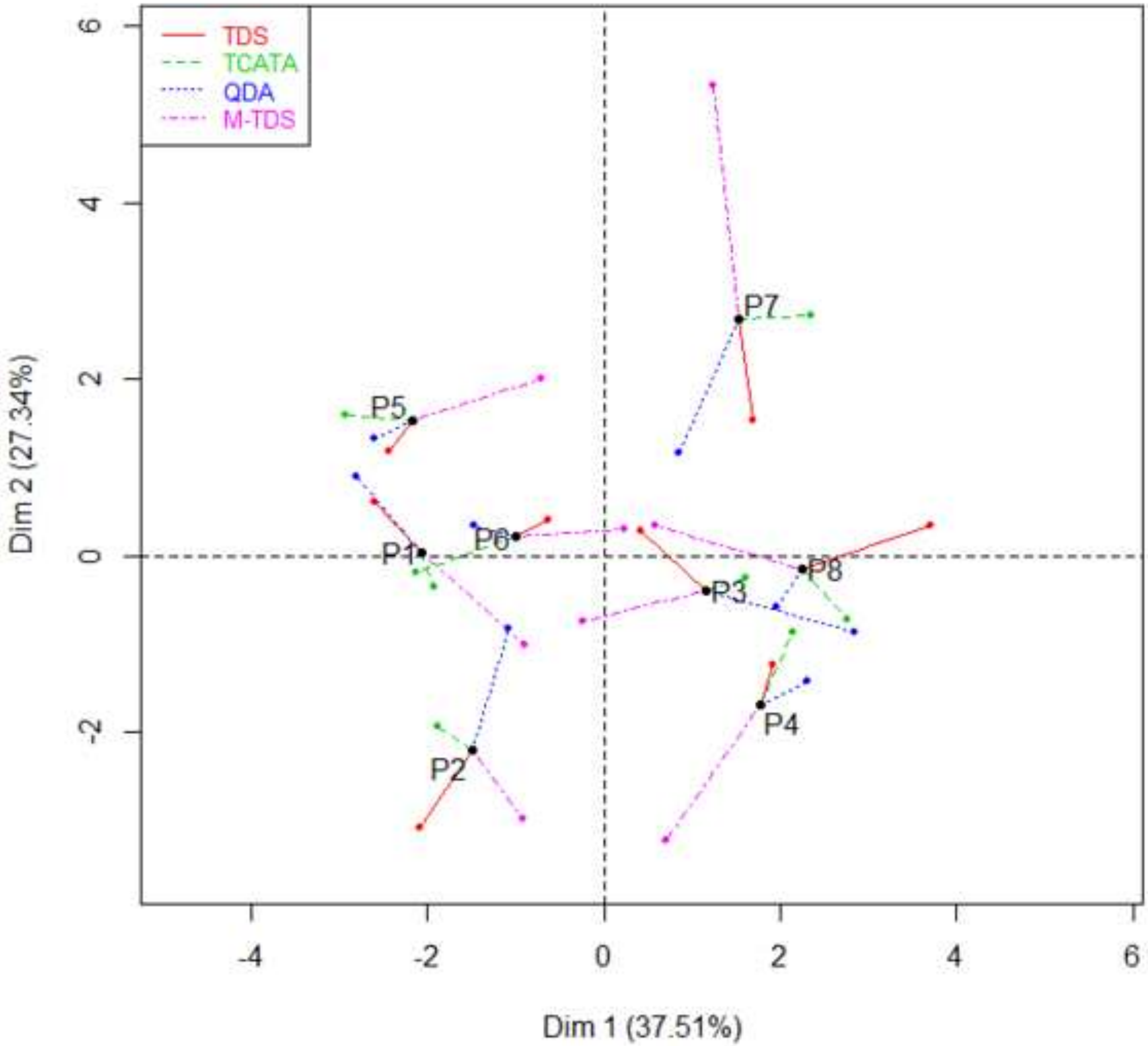

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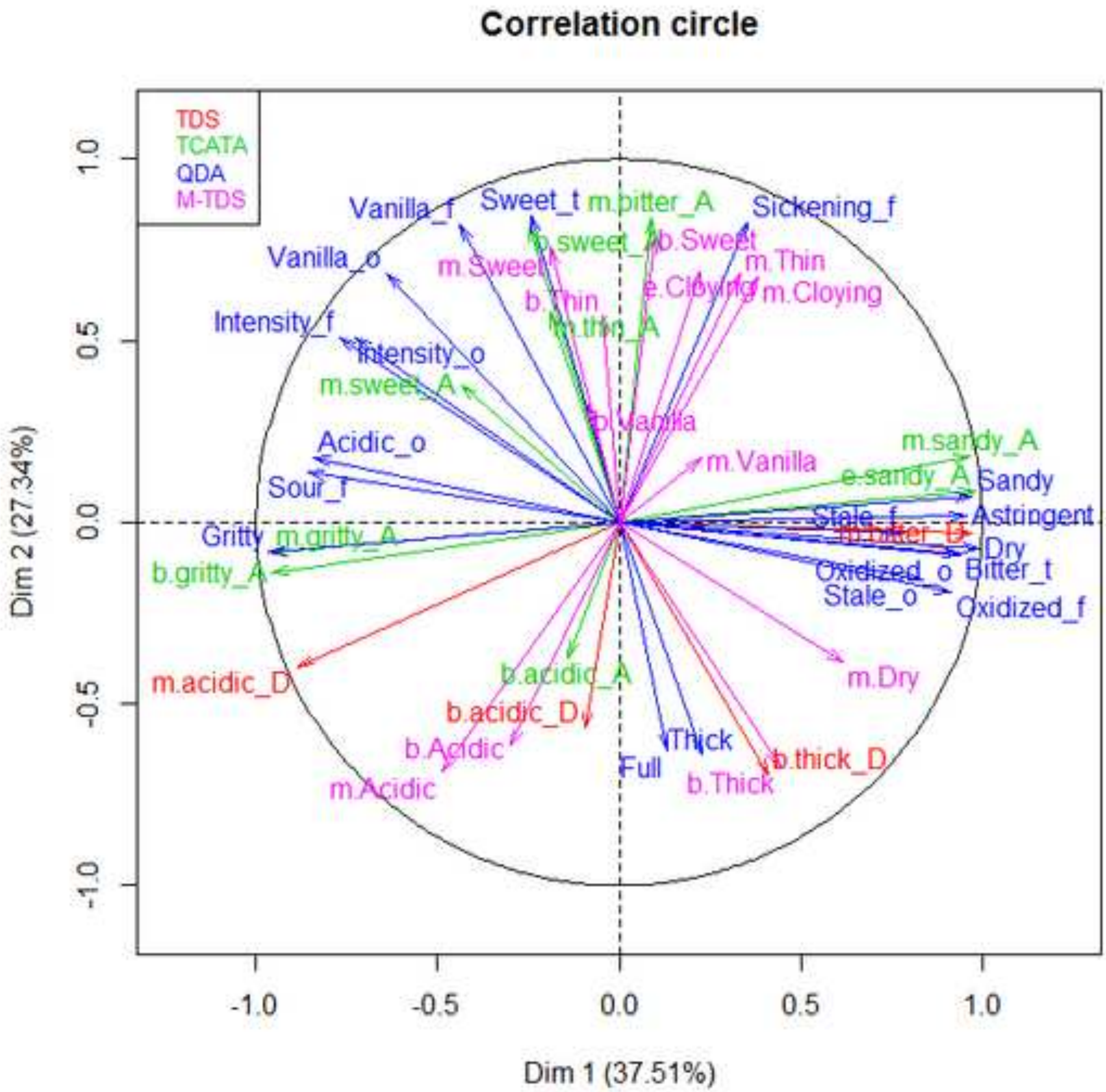

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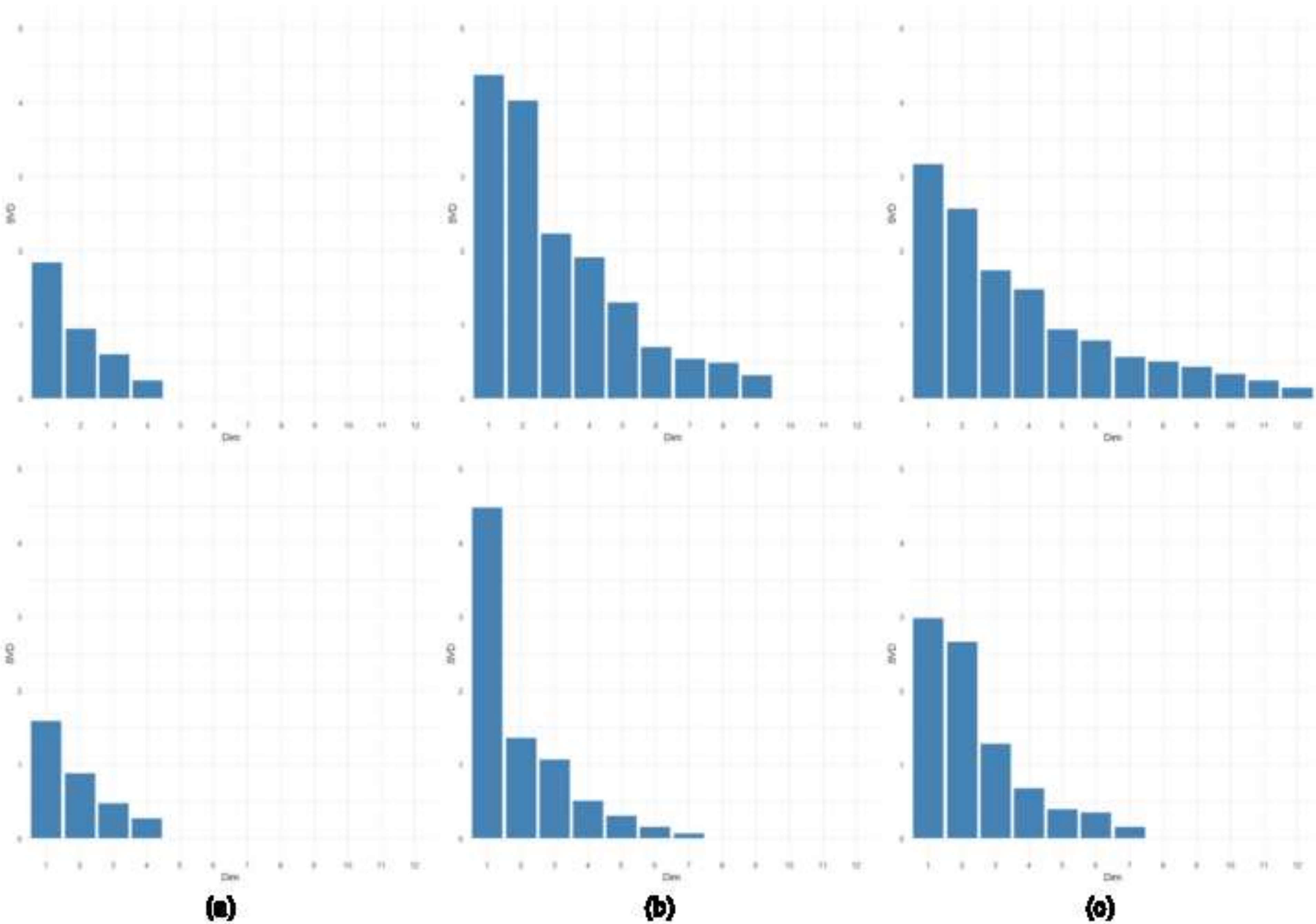

Figure 6a
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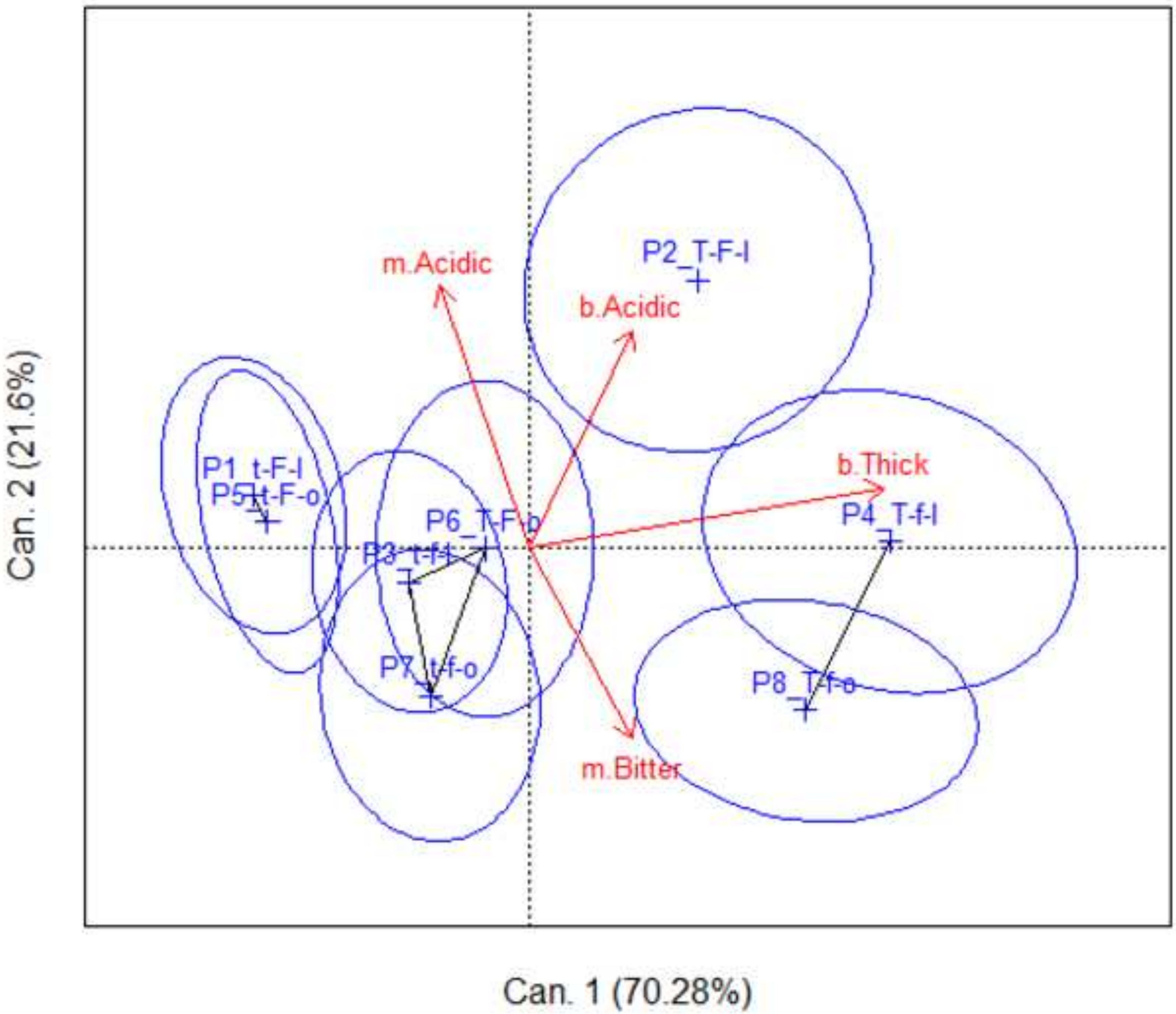

Figure 6b
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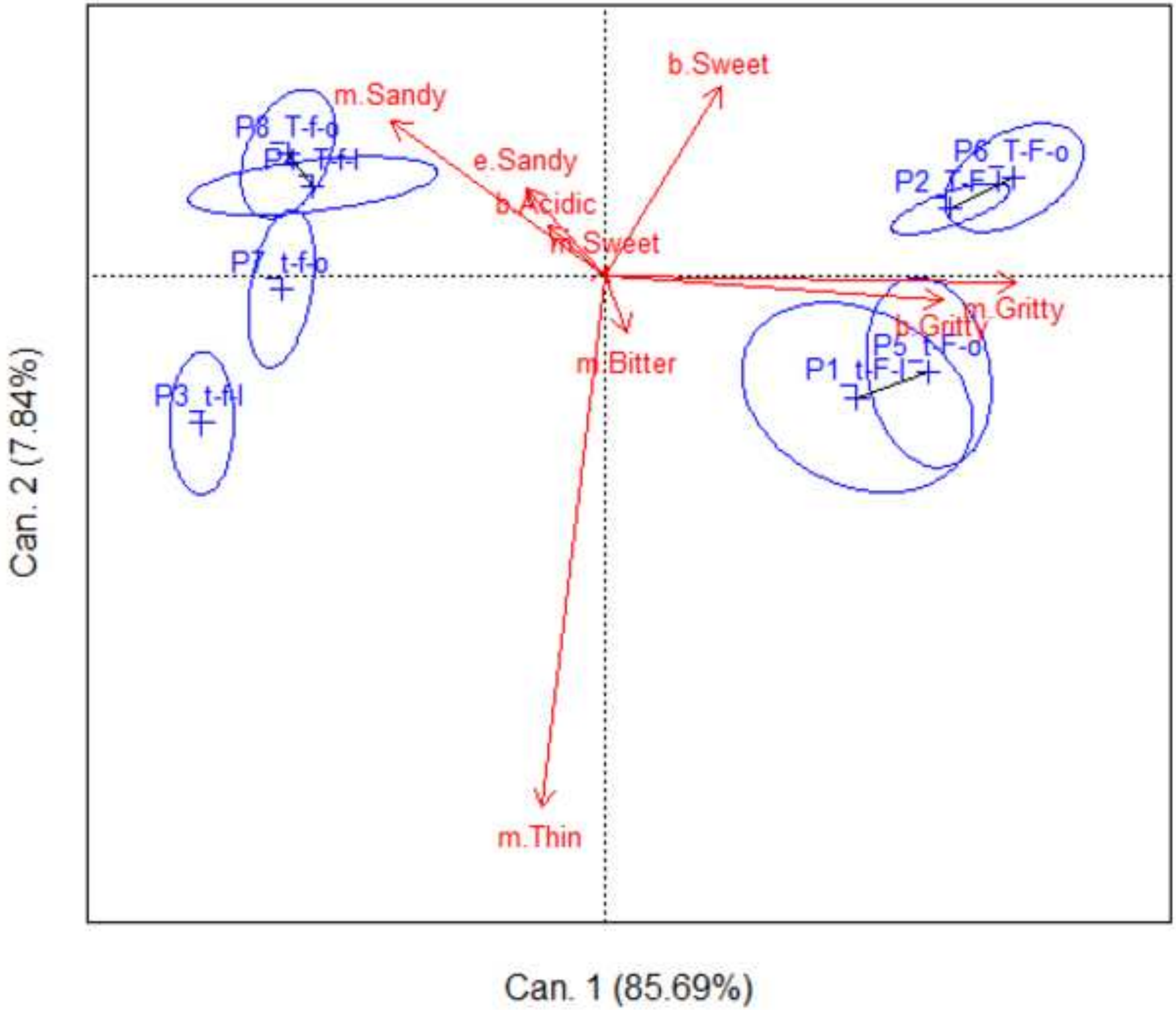

Figure 6c

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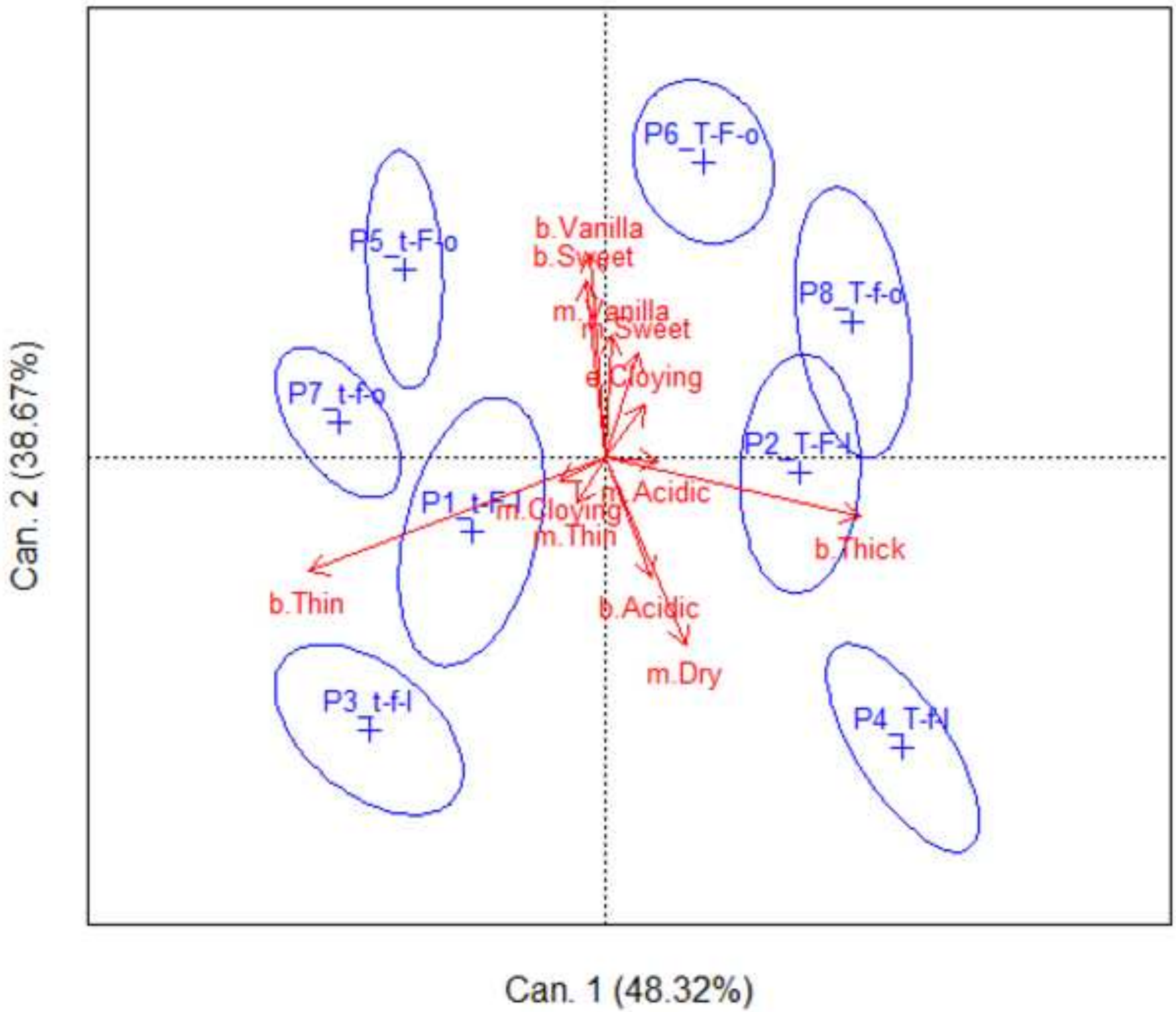

Supplementary Data_TDS_P1
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Supplementary Data_TDS_P2

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Supplementary Data_TDS_P3
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Supplementary Data_TDS_P5

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Supplementary Data_TDS_P6

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Supplementary Data_TCATA_P1

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