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## Contribution of temporal dominance of sensations performed by modality (M-TDS) to the sensory perception of texture and flavor in semi-solid products: A case study on fat-free strawberry yogurts

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### ABSTRACT

This study aimed to perform Temporal Dominance of Sensations by modality (M-TDS) combined with a multi-intake approach to investigate texture and flavor perception in semi-solid products. Trained panelists ( $n = 15$ ) evaluated fat-free strawberry yogurts enriched with functional proteins involving texture modifications. As yogurt is a semi-solid product, its in-mouth residence time is short. A multi-intake approach was therefore expected to give more reliable information about the sensory properties perceived by panelists. The two modalities of texture and flavor were analyzed separately to characterize the effect of added proteins. Trials were made according to an experimental design with two factors (protein type and concentration) and three levels each. Different statistical treatments, taking or not the temporality of attributes into account, were performed on standardized and non-standardized data. The implementation of M-TDS was essential to highlight differences of flavor perception in addition to the more evident texture modifications. The study of sensory trajectories evidenced that texture modifications, induced by the use of different whey proteins, slightly modified the perception of flavor and sweetness. The global flavor perception of the samples varied with the number of spoons, which particularly impacted the taste attributes. This study highlighted the importance of using M-TDS when studying texture and flavor in semi-solid products, and the relevance of the multi-intake approach to characterize flavor perception. This methodology enabled panelists to evidence both marked texture differences and subtler flavor modifications, and these useful data were emphasized by combining different statistical treatments.

### 1. Introduction

The sensory properties of food products are key factors determining their acceptance by consumers. The different perceptions such as texture, taste and flavor are integrated during consumption and influence consumer pleasure. Different processes, such as mastication, salivation or tongue movements, happen during consumption, leading to a complete transformation of the food ingested. The perception of texture is therefore a dynamic process, but flavor intensity and quality are also highly influenced by the in-mouth transformations (Di Monaco, Su, Masi, & Cavella, 2014). In this context, temporal sensory methodologies appear to be essential to truly understand consumer's perceptions and their hedonic responses.

Temporal Dominance of Sensations (TDS) is a methodology

developed to obtain temporal information for several attributes during product consumption (Pineau et al., 2009). It allows the comparison of the attributes perceived simultaneously in complex food matrices (Bruzzone, Ares, & Giménez, 2013). TDS is based on the concept of dominance. The dominant attribute being the attribute that attracts the attention of the panelist, even if it is not the most intense (Schlich, 2017). TDS has been applied on a large range of products such as coffee (Dinnella, Masi, Naes, & Monteleone, 2013), yogurts (Bruzzone et al., 2013; Mesurolle, Saint-Eve, Déléris, & Souchon, 2013), cereals (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009), or cheese (Rodrigues, de Souza, Lima, da Cruz, & Pinheiro, 2018), but few studies have been conducted with the objective of studying the perception of several sensory modalities (i.e. texture, taste and flavor) in the same product through consumption.

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TDS performed by modality (M-TDS) is an adaptation of the TDS methodology, which has been designed to overcome the difficulty for assessors to decide on both the modality and the attribute during the TDS task (Agudelo, Varela, & Fiszman, 2015; Nguyen, Næs, & Varela, 2018). M-TDS was applied on fruit fillings (Agudelo et al., 2015), on commercial cheeses (Rodrigues et al., 2018) and on yogurts (Meyners, 2019). It is well established that interactions exist between the different sensory modalities, and that a texture modification will most certainly have an impact on the perception of flavor. However, studying several modalities simultaneously and having to cite the dominant attribute can quickly become a difficult task for panelists. In their study on cheeses, Rodrigues et al. (2018) compared the simultaneous and the separated evaluation of texture and taste attributes in TDS. They noted that taste attributes were only dominant in the separated evaluation, and that the time at which attributes reached significance was different between the two methods. The assessors taking part in the study indicated that the separate evaluation was easier and more reliable than the simultaneous one. Moreover, Meyners (2019) showed that M-TDS discriminated yogurts both on texture and flavor attributes, whereas TDS identified differences only based on texture attributes. Yogurt is a useful model food to study because it is a complex product, offering a wide range of textures with the possibility of being flavored. It has a semi-solid texture, for which little mastication is required, and which is quickly de-structured by tongue movements (Mesurrolle et al., 2013). The standard procedure is to perform M-TDS during the first spoon, but a way to adapt M-TDS methodology to the short in-mouth period could be to use a multi-intake approach. This solution is also appropriate to evaluate flavored food products. Indeed, repeated bites can change the perception of the product due to sensory adaptation or to flavor persistence. For instance, the use of a multi-bite approach have enabled the identification of changes in the temporal profile of juices (Zorn, Alcaire, Vidal, Giménez, & Ares, 2014).

In this context, the objective of the study was to combine the M-TDS methodology with the multi-intake approach to investigate the changes of perception due to the use of innovative functional whey protein aggregates in yogurts. These functional aggregates are meant to be used as natural texturizing ingredients, and the subtle change of the protein aggregation state has been shown to be efficient to modulate texture (Lesme et al., 2019). The study focuses on the dynamics of texture and flavor perception during consumption of strawberry-flavored yogurts, a model of semi-solid food products.

## 2. Materials and methods

### 2.1. Raw materials

Low-heat spray dried skimmed milk powder (34% proteins, < 1.5% fat, 8.5% ash) and Whey Protein Isolate (WPI) (86.51% proteins including 1.98% caseins, 0.4% fat, 1.92% ash) were kindly supplied by local dairy companies (confidential origin). The composition of the powders is given according to the manufacturers' information. Food grade sodium chloride (NaCl) and sodium hydroxide were bought from Sigma Aldrich (Saint-Louis, USA). YFL-812 (Chr Hansen, France) was used as starter culture because of its low ability to produce exopolysaccharides. Milli Q (Merck Millipore, Burlington, USA) water was used for the production of WPI solutions and functional aggregates FA. All ingredients were food-grade.

### 2.2. Experimental design

In the following text, the term "yogurt" will be used to mean "fat-free set-type strawberry yogurt". Two factors were studied: the type and the concentration of protein added in the yogurts (Table 1). Regarding the type of protein studied, yogurts were either enriched with native whey protein isolate (WPI), monodisperse functional aggregates (MFA) or polydisperse functional aggregates (PFA). These proteins were

**Table 1**

Experimental design. Yogurts were enriched with either Whey Protein Isolate (WPI), Monodisperse Functional Aggregates (MFA) or Polydisperse Functional Aggregates (PFA). The two types of aggregates were obtained in controlled conditions from a WPI solution. Three different concentrations (0.5%, 1.5%, 2.5%) were used to modify the yogurt texture.

		Type of protein		
		WPI	MFA	PFA
Concentrations of proteins added in the yogurts (%)	0.5%	WPI05	MFA05	PFA05
	1.5%	WPI15	MFA15	PFA15
	2.5%	WPI25	MFA25	PFA25

incorporated in the yogurts in three different concentrations: 0.5%, 1.5%, and 2.5%.

### 2.3. Sample manufacture

In this study, MFA and PFA were compared to native WPI.

#### 2.3.1. Whey protein aggregates

MFA and PFA were produced according to Lesme et al. (2019). These two types of aggregates were obtained by varying the ionic strength of the protein solution. A low ionic strength (15 mM) led to MFA (population with a diameter of 200 nm) whereas a higher salt concentration (45 mM) led to PFA (population with a diameter of 200 nm and population with a diameter of 1000 nm).

#### 2.3.2. Yogurts manufacture

Skimmed milk was reconstituted to 100 g kg<sup>-1</sup> milk solids using low-heat spray-dried skimmed milk powder. The reconstituted milk was stored overnight at 4 °C to allow hydration of the powders. After being heated at 90 °C for 5 min, the milk was cooled to the fermentation temperature (43 °C) and inoculated with the yogurt starter culture. At this point, 5% sugar (w/w) was added to the milk. Yogurts were also flavored with 0.05% (w/w) strawberry flavoring containing 20 odorous compounds mixed in propylene glycol (Mane & Fils, France). The concentration of the odorous compounds ranged from 0.1 mg kg<sup>-1</sup> to 30 mg kg<sup>-1</sup> of yogurt.

During yogurt manufacture, the milk was enriched either with WPI, MFA or PFA which were added either before or after heat treatment of the milk (Table 1). The mix was conditioned in glass cups of 40 mL and put in an incubator for fermentation at 43 °C during about 6 h until the pH reached 4.6.

### 2.4. Temporal dominance of sensation by modality

#### 2.4.1. Ethics

The sensory tests were conducted in accordance with the Declaration of Helsinki. All applicable institutional and governmental regulations concerning the ethical use of human volunteers were complied with during this research study. Assessors gave written consent after reading detailed information about the study. The sensory tests performed in this study were approved by the ethics evaluation committee of INSERM (IRB00003888, IORG0003254, FWA00005831).

#### 2.4.2. Panel and training

The sensory panel consisted of fifteen trained assessors (2 males, 13 females) aged between 20 and 50 years old. Since a confusion between the concepts of intensity and dominance can exist (Varela et al., 2018), this panel was exclusive to TDS and the panelists did not perform QDA.

The first session was dedicated to the generation of vocabulary and associated definitions for texture and flavor properties. During this session, panelists tasted the nine yogurts to discover the product space, and generated vocabulary. Only the most frequently quoted attributes

**Table 2**

Definitions of the attributes used for TDS measurements. These descriptors were cited by the trained panel to describe the texture and the flavor of the yogurts.

Attributes	Definitions
Firmness ( <i>Ferme</i> )	Describes the resistance of the yogurt when it is crushed between the tongue and the palate
Liquid ( <i>Liquide</i> )	Describes the tendency of yogurt to flow in the mouth
Viscous ( <i>Visqueux</i> )	Describes a smooth and homogenous texture with an intermediate thickness
Melty ( <i>Fondant</i> )	Rate at which the yogurt loses thickness in the mouth. Tendency to create a paste in the mouth
Brittleness ( <i>Cassant</i> )	Sensation linked to the difficulty of mixing the yogurt with saliva when it loses its thickness
Graininess ( <i>Granuleux</i> )	Describes the presence of particles or granules
Sweet ( <i>Sucré</i> )	Sensation associated to sweet taste (e.g. sucrose)
Sour ( <i>Acide</i> )	Sensation associated to a sour taste (e.g. citric acid)
Lemon ( <i>Citron</i> )	Describes the perception of the taste of lemon
Green strawberry ( <i>Fraise verte</i> )	Describes the flavor of a strawberry not ripe enough and slightly sour
Cooked strawberry ( <i>Fraise cuite</i> )	Describes the flavor of a cooked strawberry, similar to strawberry jam
Wild strawberry ( <i>Fraise des bois</i> )	Describes the flavor of wild strawberry
Milky ( <i>Lacté</i> )	Taste of milk
Caramel ( <i>Caramel</i> )	Caramel, grilled notes
Chemical ( <i>Chimique</i> )	Describes the perception of a fruity flavor that doesn't seem to be natural

were selected. Six texture attributes and nine flavor attributes were chosen (Table 2).

During the next session, assessors were trained on the notion of temporality of sensations, on the TDS method, and especially on the concept of dominance. A dominant descriptor was defined as a descriptor that triggered the most the attention of the taster at a given time. As defined by Schlich (2017), it may not be the most intense attribute. This notion was explained to the panelists who were also familiarized with the procedure of evaluation on the computer.

During the next two sessions, assessors practiced the attributes of texture and flavor separately by tasting the nine yogurts of the study in order to establish a consensual definition of the attributes. For each attribute, a definition was defined with the panel in order to ensure that the panelists associated the same descriptor with the same sensation. Physical references were used to help panelists understanding the attributes. Commercial products were used as references to help assessors differentiate between “viscous” and “melty”, “firmness” and “brittleness”, “cooked” and “green” strawberry notes.

During all the training sessions, panelists were familiarized with the TDS methodology and the use of the computer system. Special care was taken to standardize the multi-intake protocol, and panelists were asked to evaluate the three spoons of yogurts without taking a break to be as close as possible as real consumption conditions. During these sessions, panelists could also become familiar with the “swallow” button, and practice clicking on the button when they had to swallow.

The replicability of the panelists was assessed by repeating two yogurts (a very firm one WPI25 and a smoother one PFA05) at each training session and by comparing the TDS curves obtained. As stated by Pineau et al. (2009), the dominance rates can be seen as a reflection of consensus among judges and therefore a measurement of panel performance.

#### 2.4.3. Evaluation conditions

The nine yogurts were evaluated in duplicate in eight sessions of evaluation, with four sessions dedicated to texture evaluation and four sessions dedicated to flavor evaluation. Texture and flavor perceptions were evaluated by using the list of attributes (Table 2). Panelists evaluated five yogurts per session, except for the last session where three yogurts were tested. For each yogurt sample, they consumed three spoons because of the multi intake approach. The presentation order of the nine yogurts was randomized and all the panelists alternated with a session dedicated to texture evaluation and a session dedicated to flavor evaluation. Yogurt samples were coded with three-digit numbers, served in glass-cups containing 40 mL of yogurt, and randomized into the sessions.

#### 2.4.4. Tasting protocol

The tasting protocol for each sample was the same. Assessors were instructed to click on the “Start” button as soon as they had a spoon of yogurt in their mouth. They had to select the attributes they perceived as dominant from the list of attributes during the consumption of the sample. They were briefed to click on the “Swallow” button when they had to swallow. After that, they could select again attributes perceived as dominant. This was particularly relevant for aroma evaluation as the aftertaste is an important component of aroma perception. Only one attribute at a time could be selected, but assessors were free to select the same attribute several times over the consumption period. The order of presentation of attributes was different for each panelist, to balance the fact that the first attribute on the list could be more cited (Meillon, Urbano, & Schlich, 2009). A time limit was put after 30 s of evaluation, which is a long time for the consumption of a spoon of yogurt, and which enabled assessors to continue to describe their perception until no sensation was dominant anymore. Assessors could select the “Stop” button to end the test before the automatic end of evaluation if they did not perceive a dominant sensation anymore. Panelists performed the same tasting protocol for the second and third spoons immediately after having evaluated the first spoon, according to the protocol of Zorn et al. (2014). Taking three spoons in a row was chosen for the multi-intake approach as it had already been used in several studies using the same methodology (Galmarini et al., 2017; Oliveira et al., 2015; Zorn et al., 2014). Panelists were asked to always take the same quantity of yogurt in the spoon, which corresponded to a full spoon. However, no measurement of the actual quantity eaten by each panelist was done. Three TDS profiles were obtained for each yogurt sample and each consumer for the two replicates performed. Panelists rinsed their mouth with Evian water and ate unsalted crackers during a one-minute break between the different yogurt samples.

#### 2.4.5. Statistical treatment

Data acquisition was carried out on a computer with Fizz software (Biosystèmes, 1990). Data analysis was performed using the XLSTAT software (Addinsoft, Andrenarcht, Germany, 2017) and R version 3.5.1 (R Core Team, 2016).

The total duration of the evaluation, the consumption duration (time needed to swallow the yogurt) and the time before clicking on the first descriptor at the beginning of the test were extracted from the non-standardized data. A two way anova with interactions was carried out with product and spoon factors considered as fixed effects and subject factor as random effect. If a significant difference was observed ( $\alpha = 0.05$ ), the least significant difference (LSD) test was run to establish differences between means.

Assessors exhibited different consumption behaviors with different

consumption periods. The standardization of the individual curves was inspired by the method used for time-intensity curves (Liu & MacFie, 1990). Curves were normalized in the time direction to have the same time of first click ( $t_{start} = 0$ ) and time of swallowing ( $t_{swall} = 100$ ). For each curve, the time value  $t$  was transformed to

$$100 \times \frac{t - t_{start,i}}{t_{swall,i} - t_{start,i}} \quad (1)$$

where  $t_{start,i}$  and  $t_{swall,i}$  represent, respectively, the time of the first click and the time of swallowing for the subject  $i$ . In our study, the time after swallowing was relevant to characterize the aftertaste perceived in the evaluation of flavor. As a consequence, the coefficient calculated in Eq. 1 was applied on the attributes selected from swallowing to the end of evaluation of each panelist. Therefore, the consumption period (standardized time between first click and swallowing) was the same over the panel, whereas the global evaluation period (consumption period and aftertaste evaluation) differed between panelists.

For each product, the dominance rate (the proportion of subjects that selected each attribute) was computed at each time point on the standardized data, and TDS curves were represented over the three spoons. As TDS curves were performed on the standardized data, the differences of behavior observed between products regarding total consumption duration and time needed to click on the first descriptor were hidden. However, a higher consensus was obtained between judges, and the comparison between texture and flavor perception was made possible. A high dominance rate indicates a high consensus between the panelists at a given time. Dominance rate for each attribute was smoothed using a polynomial spline line type with the R package tempR (Castura, 2016). It has to be noted that despite the smoothing performed on the dominance rates, clicking on the swallowing button induced a decrease of the dominance rate before swallowing. One could imagine that the last attribute selected before the swallowing event stays dominant just after it. However, clicking on the swallowing button was an important step of the procedure and it was likely to influence the perception of the panelists. This is why the drop of the dominance rate towards zero at the swallowing time was represented in the curves. As suggested by Pineau et al. (2009), two lines were drawn on the TDS graph: chance level and significance level. Chance level ( $P_0$ ) is the dominance rate that an attribute can obtain by chance considering all the attributes evaluated. The value  $P_0$  is equal to the inverse of the total number of attributes. Indeed, at each point of the standardized consumption period, each judge had no other choice than selecting one of the attributes. Significance level ( $P_s$ ), is the minimum value of a dominance rate an attribute has to obtain to be significantly higher than  $P_0$  (binomial distribution,  $\alpha = 0.05$ ). The study of the TDS curves performed on standardized data complemented the analysis performed on the non-standardized data, and enabled to reach a higher consensus between judges and the comparison between texture and flavor perception. With standardized data, the comparison between those two modalities was easier although some information like the time needed

to click on the first descriptor were not yet reflected.

In addition to TDS curves and their visual descriptions, dominance duration was computed at individual level by adding the time periods during which an attribute was perceived as dominant (Galmarini, Visalli, & Schlich, 2017). It is worth noting that the analysis of dominance duration doesn't take into account the time at which the attribute has been perceived.

Multidimensional differences were represented by a Principal Component Analysis (PCA) to compare the yogurt samples. Confidence ellipses obtained by bootstrapping the subjects, were drawn to represent the distribution of the evaluations by assessor around the mean. The spoons of yogurts were projected on the PCA in order to represent their evolution within each product.

A PCA was also performed on the standardized data to show sensory trajectories over the time of consumption. Carrying out the PCA on the standardized data was important to enable the comparison between the texture modality and the flavor modality as their evaluation duration differed a lot. According to the procedure described by Lenfant et al. (2009), the observations of the PCA performed on the standardized data were the dominant rates of each time-point and for each product. The variables were the sensory attributes. For the evaluation of texture, 4 equally-spaced time points were taken over the consumption period of each sample. As no attribute was dominant after swallowing, the time after swallowing was not taken into account in the analysis. However, for the evaluation of flavor, 4 equally-spaced time points were taken until swallowing, and another point was taken at the end of the evaluation to analyze the perception of the aftertaste. Two distinct PCA were performed to describe texture and flavor trajectories separately.

### 3. Results

#### 3.1. Key periods in the non-standardized data to characterize the yogurt samples

The first step to get information on the relevance of the protocol implemented and to characterize the products is to focus on the non-standardized data.

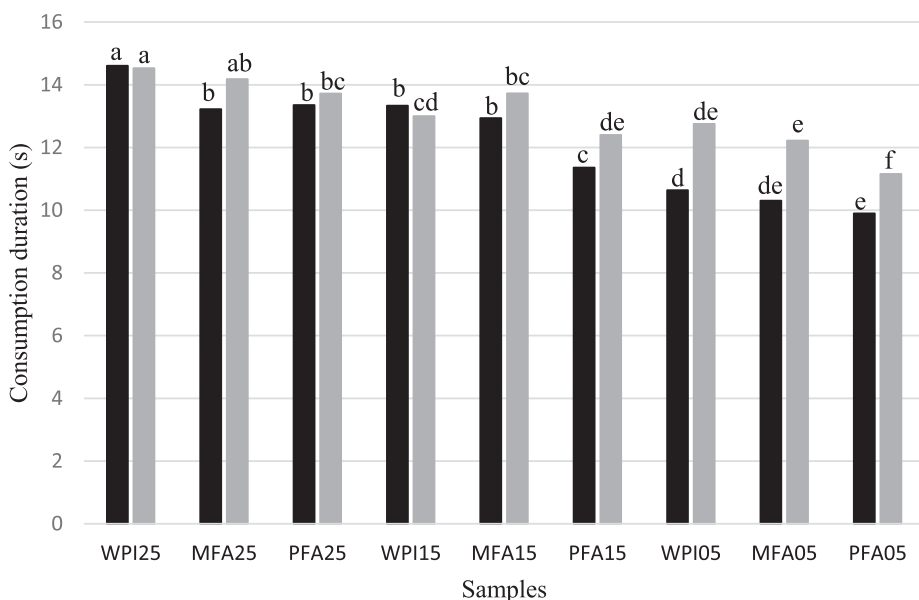
Consumption durations varied from 9.89 s to 14.6 s depending on the yogurt samples. Anova evidenced significant differences among yogurts ( $p < 0.0001$ ) (Table 3), and multiple comparison tests highlighted different groups of yogurts (Fig. 1). Assessors were a significant source of variation ( $p < 0.0001$ ) regarding the consumption time and the time to click on the first descriptor. The significance of the assessor effect reflects the important variability of food oral processing among panelists, and training did not completely succeed in erasing the differences. The significant interaction assessor\*sample indicated that the variability between assessors had an impact on their samples evaluation. The standardization performed on the data was a way to overcome as much as possible these inter-individual differences (Lenfant et al., 2009). A correlation between consumption time and texture was

**Table 3**

Analysis of variance results for the effects of sample and spoon on the time to click on the first descriptor and on the time before swallowing (non-standardized data). The two times were evaluated for texture and flavor.

	Modality	Effect <sup>b</sup>					
		Assessor	Sample	Spoon	Assessor*sample	Assessor*spoon	Sample*spoon
Time to click on the 1st descriptor	Texture	<b>68.069</b> < 0.0001	<b>46.636</b> < 0.0001	<b>14.507</b> < 0.0001	<b>2.369</b> < 0.0001	<b>1.654</b> <b>0.019</b>	<b>1.259</b> <b>0.218</b>
	Flavor	<b>90.336</b> < 0.0001	<b>4.839</b> < 0.0001	1.603 0.202	1.855 < 0.0001	<b>2.325</b> <b>0.000</b>	0.613 0.875
Consumption duration	Texture	<b>149.00</b> < 0.0001	<b>46.636</b> < 0.0001	<b>17.332</b> < 0.0001	<b>2.260</b> < 0.0001	0.819 0.733	0.593 0.890
	Flavor	<b>99.248</b> < 0.0001	<b>14.818</b> < 0.0001	<b>3.435</b> <b>0.033</b>	<b>1.475</b> <b>0.002</b>	<b>1.520</b> <b>0.043</b>	0.795 0.692

<sup>b</sup> Values in bold correspond to significant effects at the level 0.05.



**Fig. 1.** Consumption duration (in seconds) averaged across subjects extracted from the non-standardized data. The consumption duration corresponded to the difference between the swallowing time and the time of the first click on a descriptor. The evaluation of texture is represented in black and the evaluation of flavor is represented in grey. Different letters account for significant difference according to LSD test.

observed. For each type of protein studied, the higher protein concentration, which corresponded to the firmest yogurts (Lesme et al., 2019), induced a longer consumption time. The firmest yogurt requiring the longer consumption time for both texture and flavor evaluation was WPI25. Generally, yogurts containing WPI needed a longer consumption time compared to yogurts enriched with PFA and MFA because of their texture (Lesme et al., 2019). Moreover, the modality assessed had an impact on the consumption duration. The latter tended to be longer for flavor evaluation than for texture evaluation, especially for yogurts enriched with 0.5% of proteins. Assessors needed approximately ten seconds for texture evaluation, whereas the consumption time reached more than 12 s to evaluate the flavor of the same yogurts.

As shown in Fig. 2, the time needed to click on the first descriptor was much longer for flavor analysis than for texture. For instance, it was more than doubled for the evaluation of WPI25 between texture and flavor evaluation. The time needed for the release of sensory active compounds from yogurt matrices is one possible explanation of this difference. Texture was perceived right after putting the samples in the

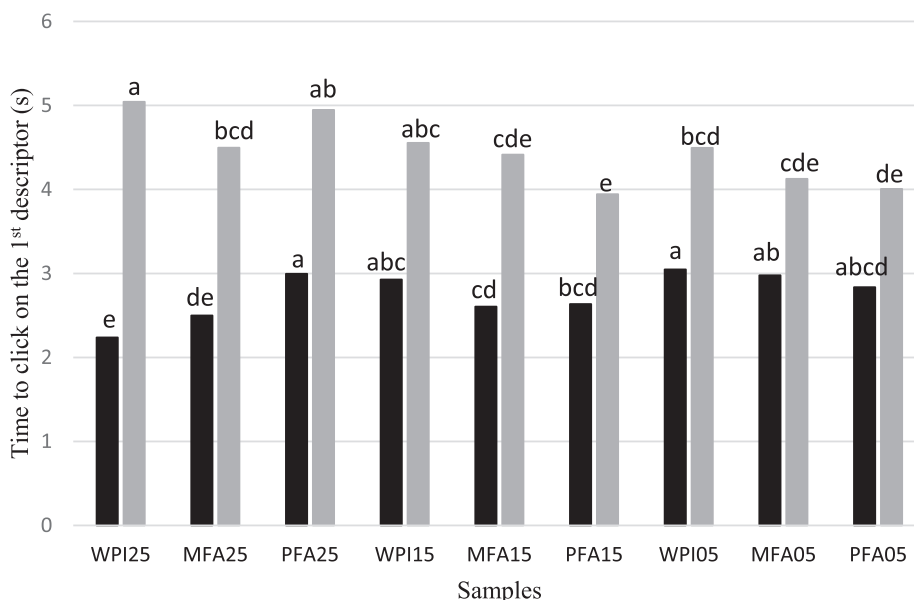
mouth, whereas a delay was observed for flavor perception because of the progressive release of taste and aroma compounds. The time needed to click on the first descriptor significantly increased with the rise of protein concentration (Fig. 2). The release of flavor compounds depended on the protein concentration and might be influenced by texture modifications.

As shown in Table 3, the consumption time and the time taken to click on a first descriptor were influenced by the number of spoons. Assessors tended to swallow faster the yogurts as successive spoons were taken. This effect was found to be more marked for texture than for flavor (Table 3). It can be hypothesized that panelists got used to the sample and that they performed the TDS task easily when going from the first to the third spoon.

### 3.2. The Multi-intake approach

#### 3.2.1. Texture

It appeared from the three-way anova on the texture attributes



**Fig. 2.** Time before the 1st click on a descriptor (in seconds) averaged across subjects extracted from the non-standardized data. The evaluation of texture is represented in black and the evaluation of flavor is represented in grey. Different letters account for significant difference according to LSD test.

**Table 4**

Three-way analysis of variance performed on the dominance duration of the attributes of texture. The F-values and the p-values (italic) are reported in the table.

Attributes	Effect <sup>a</sup>					
	Assessor	Sample	Spoon	Assessor*Sample	Assessor*spoon	Sample*spoon
Firmness	<b>14.4028</b> < <b>0.0001</b>	<b>36.1145</b> < <b>0.0001</b>	0.0780 0.9523	<b>5.2078</b> < <b>0.0001</b>	0.4882 0.9885	0.6801 0.8151
Liquid	<b>7.8899</b> < <b>0.0001</b>	<b>95.4104</b> < <b>0.0001</b>	0.1290 0.8790	<b>3.2006</b> < <b>0.0001</b>	0.7070 0.8684	0.3111 0.9957
Viscous	<b>17.6484</b> < <b>0.0001</b>	<b>61.1058</b> < <b>0.0001</b>	0.2584 0.7724	<b>5.1362</b> < <b>0.0001</b>	0.5243 0.9804	0.2146 0.996
Brittleness	<b>13.7920</b> < <b>0.0001</b>	<b>106.1779</b> < <b>0.0001</b>	1.2181 0.2965	<b>5.0216</b> < <b>0.0001</b>	0.7104 0.8650	0.5100 0.9428
Melty	<b>13.0483</b> < <b>0.0001</b>	<b>21.2284</b> < <b>0.0001</b>	0.2282 0.7961	<b>4.6693</b> < <b>0.0001</b>	0.5212 0.9812	0.6430 0.8495
Grainy	<b>12.0887</b> < <b>0.0001</b>	<b>86.6632</b> < <b>0.0001</b>	0.5691 0.5663	<b>4.7163</b> < <b>0.0001</b>	0.4694 0.9916	0.5541 0.9174

<sup>a</sup> Values highlighted in bold indicate significant effects at level 0.001.

(Table 4) that, although the assessor\*sample interactions were significant, the F-values due to sample effect were very high, indicating that the differences observed were reliable. All the texture attributes discriminated the yogurt samples, but the multi-intake approach had no significant impact on texture perception for all the samples, texture perception was the same for the first and for each of the second and third spoons.

### 3.2.2. Flavor

Regarding flavor attributes, two aroma attributes “chemical” and “green strawberry” did not discriminate samples (Table 5). Two aroma attributes, mainly related to heating and cooking flavor notes “cooked strawberry” and “caramel” seemed to slightly differentiate the products. The taste attributes “sweet” and “sour” also slightly differentiated the products. In addition to the sample effect, it was interesting to focus on the spoon effect, which was significant for the taste attributes “sweet” and “sour” (Table 5). However, conclusions about the impact of samples and spoons on the perception of flavor attributes should be considered with caution as the F-values were often similar to those due to assessor effect. The number of spoons tended to impact the perception of “sweet” and “sour” attributes. The spoon\*sample interaction was not significant, showing that the number of spoons had the same effect independently from the yogurt considered. For all the samples, “sweet” and “sour” perceptions tended to be significantly more

dominant for the first spoon compared to the third one. The attributes related to the strawberry flavor were not influenced by the number of spoons.

### 3.3. Characterization of the products with the standardized curves of dominant rate

For this part, the dominance curves of yogurts enriched with WPI are represented in Fig. 3. The other dominance curves are shown as Supplementary material (Fig. A1 and Fig. A2). They are built from the standardized data, and the act of clicking the swallow button is represented by a decrease of the dominance rate before swallowing.

#### 3.3.1. Texture

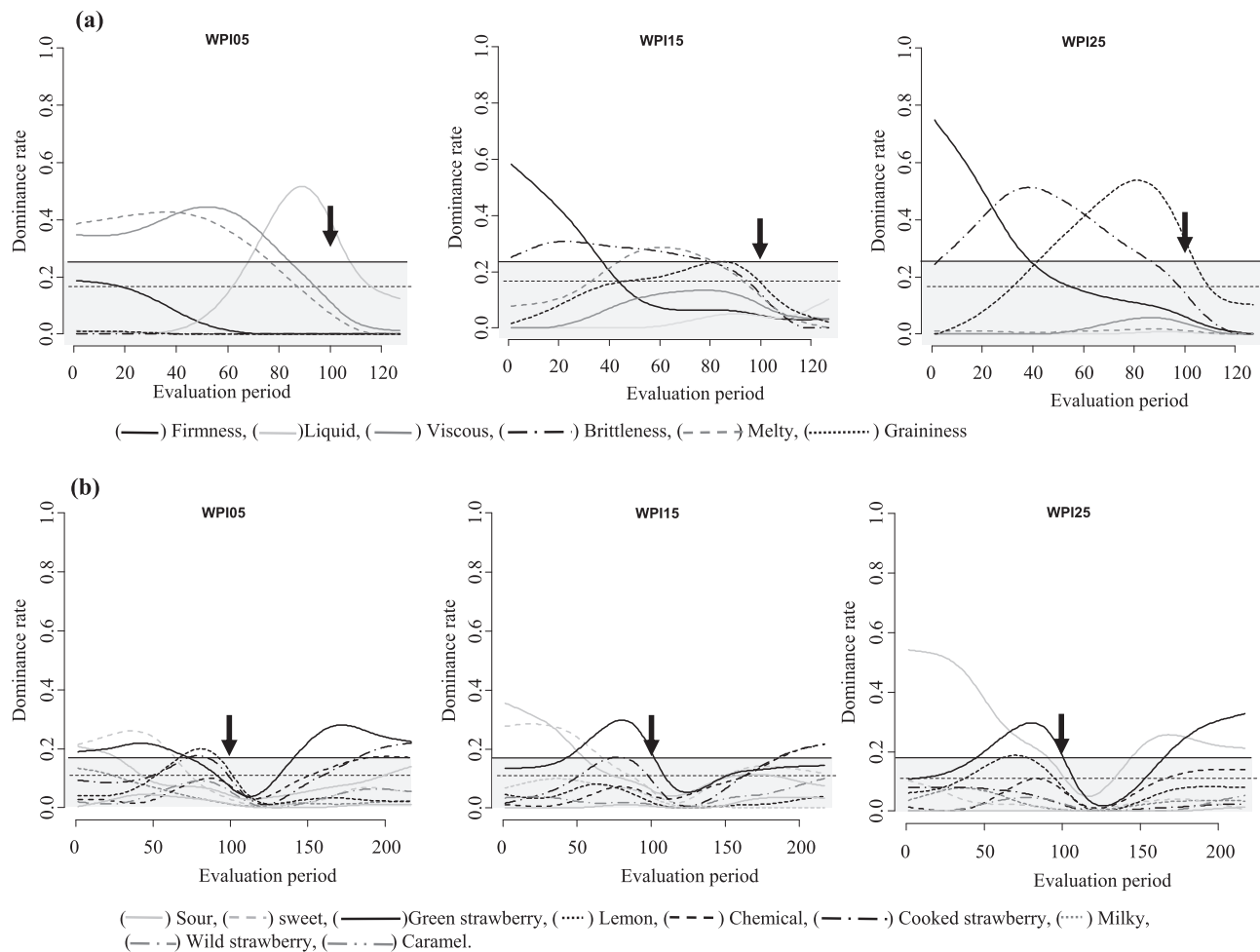
Standardized TDS curves (Fig. 3 (a)) show the dominant perceptions regarding texture for yogurts enriched with WPI, throughout the consumption period. The moment of swallowing was taken into account for standardization, therefore the point 100 of the x-axis of the standardized curves represented the standardized moment of swallowing over the panel. During the evaluation period, samples were characterized by at least three dominant texture perceptions. The sequences of dominant texture attributes were clearly different for each yogurt. WPI05 was perceived as melty and viscous in the beginning of consumption, and was perceived as liquid just before swallowing. Firmness and brittleness

**Table 5**

Three-way analysis of variance performed on the dominance durations of the attributes of flavor. The F-value and the p-value (italic) are reported in the table.

Attributes	Effect <sup>b</sup>					
	Assessor	Sample	Spoon	Assessor*Sample	Assessor*Spoon	Sample*Spoon
Sour	<b>14.55</b> < <b>0.0001</b>	<b>15.7519</b> < <b>0.0001</b>	<b>4.2003</b> < 0.05	<b>2.141</b> < <b>0.0001</b>	0.6741 0.899	0.5988 0.886
Sweet	<b>21.65</b> < <b>0.0001</b>	<b>9.9748</b> < <b>0.0001</b>	<b>0.02218</b> < 0.05	<b>2.283</b> < <b>0.0001</b>	0.9346 0.564	0.5523 0.919
Lemon	<b>12.21</b> < <b>0.0001</b>	<b>2.569</b> < <b>0.001</b>	0.7633 0.46658	<b>3.604</b> < <b>0.0001</b>	0.718 0.857	0.5055 0.945
Chemical	<b>9.886</b> < <b>0.0001</b>	1.3373 0.2218	1.5266 0.2181	<b>2.603</b> < <b>0.0001</b>	0.5269 0.98	0.3879 0.985
Green strawberry	<b>7.692</b> < <b>0.0001</b>	1.3511 0.2153	0.5154 0.5975	<b>2.765</b> < <b>0.0001</b>	0.6794 0.939	0.4331 0.974
Cooked strawberry	<b>11</b> < <b>0.0001</b>	<b>4.7617</b> < <b>0.0001</b>	0.7075 0.4933	<b>3.627</b> < <b>0.0001</b>	0.7943 0.767	0.5026 0.947
Wild strawberry	<b>3.211</b> < <b>0.0001</b>	<b>3.9817</b> < <b>0.0001</b>	0.0729 0.9297	<b>2.266</b> < <b>0.0001</b>	0.6796 1	0.4825 0.956
Milky	<b>9.84</b> < <b>0.0001</b>	<b>2.754</b> < 0.01	0.4399 0.6443	<b>2.121</b> < <b>0.0001</b>	0.3157 1	0.7792 0.71
Caramel	<b>7.046</b> < <b>0.0001</b>	<b>3.7552</b> < <b>0.0001</b>	0.8366 0.4667	<b>3.615</b> < <b>0.0001</b>	0.386 0.998	0.3955 0.9836

<sup>b</sup> Values in bold correspond to significant effects at the level 0.05.



**Fig. 3.** Standardized TDS curves of yogurts enriched with 0.5%, 1.5% and 2.5% of WPI. The dominance rate of texture attributes (a) and flavor attributes (b) are represented. Two horizontal lines account for chance level (-----) and significance level (——). The black arrow indicates the moment of swallowing.

were dominant in the first part of the evaluation period for both WPI15 and WPI25. For WPI25, the dominance rate of these two attributes reached 0.6, showing a high consensus between assessors. The same trend was present for graininess, which was dominant just before swallowing for WPI15 and WPI25, with a higher consensus reached for WPI25. For all the samples, no attribute was dominant after swallowing, which was expected since the attributes selected to describe texture refer to in-mouth sensations. Fig. A1 shows that the use of MFA and PFA induced different sequences of dominant texture attributes compared with WPI.

### 3.3.2. Flavor

The sequence of dominant flavor attributes is shown in Fig. 3(b). The point 100 on the x-axis of the standardized dominance curves represented swallowing, which happened in the first half of the evaluation period. This showed that the evaluation of the aftertaste was an important element for the evaluation of flavor perception. The temporal profile of yogurts enriched with different concentrations of WPI (Fig. 3(b)) was characterized by the dominance of sweet, sour, green strawberry, lemon and cooked strawberry, whereas other attributes such as caramel were not significantly dominant throughout consumption. The temporal profile of WPI25 was clearly different from WPI15 and WPI05. It was characterized by a maximum dominance rate higher than 50% for the attribute sour. The dominance rates of flavor attributes were lower compared to texture. This could be partially due to the higher number of flavor attributes (9 attributes for flavor and 6 for texture). A third replicate might have been useful to achieve the

optimal number of trials as recommended by Pineau et al. (2009). In addition, the complexity of the flavor profile, might make it more difficult for judges to reach a consensus. The first part of the evaluation period was dominated by taste attributes, such as “sour” and “sweet”. The attributes related to the perception of strawberry flavor appeared before swallowing, and were also dominant after swallowing, during the evaluation of the aftertaste. This trend was also true for yogurts enriched with MFA and PFA (Fig. A2).

It can be noted that the maximum dominance rate of flavor attributes (0.5) was inferior to the maximum dominance rate of texture attributes, which indicated a lower consensus between assessors.

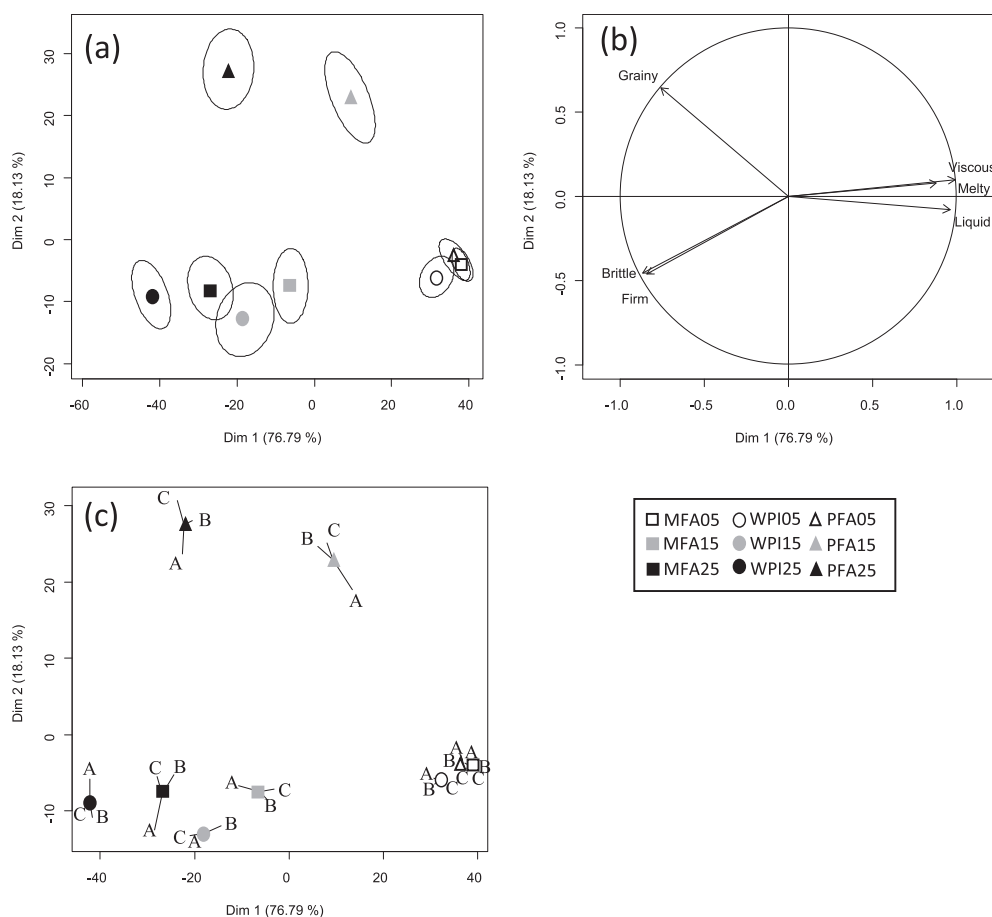
## 3.4. Characterization of the products based on the dominance duration

### 3.4.1. Texture

Fig. 4 shows the PCA on the dominance durations for texture attributes. The first and second dimensions of the PCA accounted for 96.2% of the total variability among yogurts. This representation gives information on product differences based on the duration of dominance, regardless of temporality.

PFA25 and PFA15 were the samples with the longest duration of dominance for the attribute “grainy”. These two yogurts were clearly different from the other yogurts, and this difference may be attributed to the larger aggregates present in the PFA. On the other hand, yogurts enriched with 0.5% of protein (WPI05, MFA05 and PFA05) were the ones with the longest duration of “viscous” and “melty” sensations and seemed not to be very different from each other. Finally, MFA15,





**Fig. 4.** Principal component analysis (PCA) of the dominance duration for all yogurt samples for the evaluation of texture. The PCA was performed on the standardized data. (a) Correlation plot of the observations on the average on all sips for each yogurt, an 80% confidence ellipse is drawn. (b) Plot of the variables (c) Correlation plot of the observations with the projection of the three spoons (A, B, C) for each yogurt sample.

WPI15, MFA25 and WPI25 were characterized by a long duration of firmness and brittleness. Yogurts enriched with WPI were always firmer and more brittle than yogurts enriched with MFA. Visual inspection of the ellipses allowed to see that very significant differences were present between products (Fig. 4(c)). The first dimension of the PCA was closely linked to the protein concentration added to the yogurts (Fig. 4(a)). The “grainy” sensation which characterized the second dimension was due to the addition of high concentrations of PFA in the yogurts. The projection of the spoons of yogurts on the PCA showed that texture perception did not change with the number of spoons (Fig. 4(c)). This result confirmed the previous results of the anova test where there was no significant impact of the number of spoons on texture evaluation.

### 3.4.2. Flavor

Fig. 5 shows the PCA on the durations of dominance for flavor attributes. The first two dimensions accounted for more than 83% of the variability across samples. WPI25 appeared to be clearly different from the other yogurts. It had the longest duration of sourness. PFA15 and PFA05 were the yogurts with the highest duration of “cooked strawberry” and “sweet”. PFA25 was perceived as being significantly different from PFA15 and PFA05, and appeared with a shorter duration of dominance of strawberry flavor attributes and sweetness. The same trend was found for WPI25, which was significantly different from WPI15 and WPI05 and characterized by a high dominance of “sour” and “green strawberry” attributes. On the contrary, the increasing concentration of MFA in the yogurts did not lead to a change of flavor perception. The first dimension of the PCA was linked to the protein concentration added in the yogurts. The higher the protein concentration, the lower the perception of strawberry flavor attributes. The projection of the spoons of yogurts on the PCA showed that flavor perception varied depending on the spoon, however it was difficult to

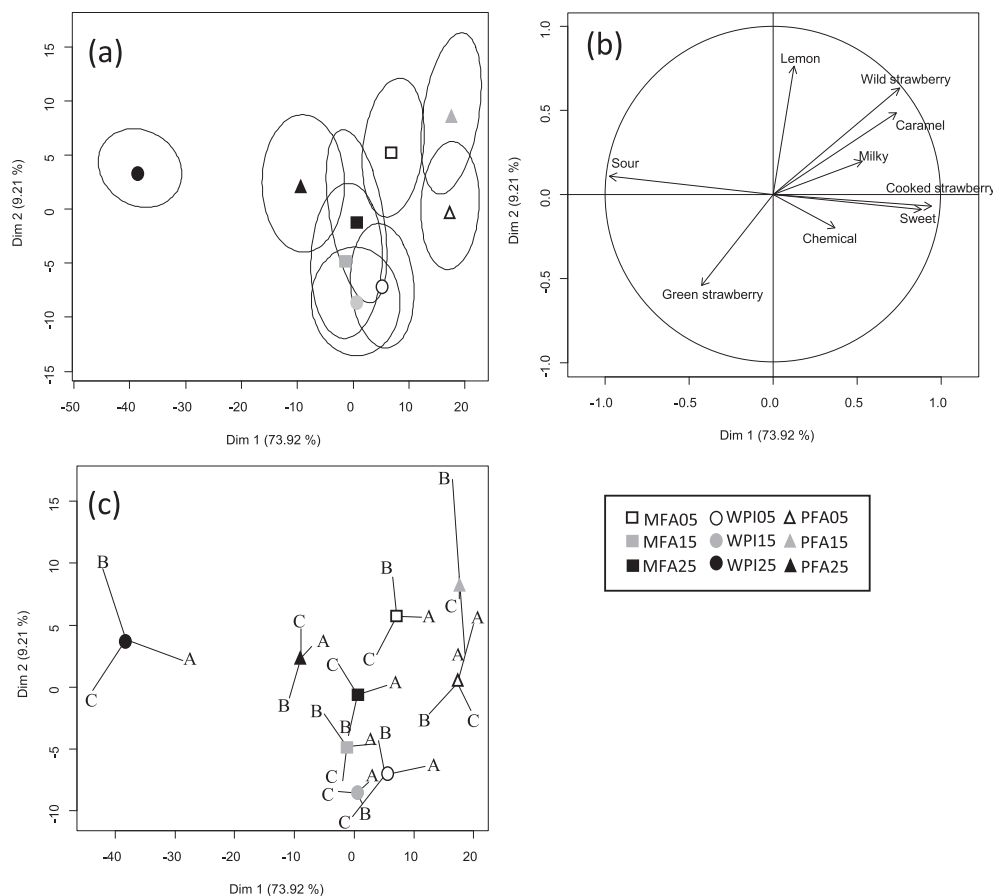
identify a clear trend among samples (Fig. 5(c)).

### 3.5. Characterization of the products with the sensory trajectories

The multivariate analysis performed with PCA evidenced product differences based on dominance duration regardless of the temporality. The representation of the sensory trajectories gave additional information about the dynamic dimension of texture and flavor perception. For clarity of the results, the PCA was performed on the mean over spoons for each yogurt sample.

#### 3.5.1. Texture

The sensory trajectories related to texture perception are represented in Fig. 6. The first two PCA components accounted for 76% of the total variance observed among the samples. The trajectories did not converge towards one point, which evidenced the existence of clear different profiles of texture among yogurts. Three different groups of products emerged from the representation: (i) a group including yogurts enriched with 0.5% of proteins which were perceived as being “melty” at the beginning of consumption and “liquid” at the end; (ii) a group including PFA15 and PFA25 showing “grainy” sensation from the beginning of consumption. This sensation was dominant throughout consumption for PFA25 whereas a “melty” sensation appeared for PFA15; (iii) a third group with yogurts for which firmness was dominant at the beginning of consumption. For yogurts enriched with 2.5% of either MFA or WPI, the “firm” sensation evolved towards a “brittle” and then to a “grainy” sensation. The dominance of firmness and graininess seemed to be even greater for WPI25 than for MFA25. The trajectories of MFA15 and WPI15 were also characterized by a dominance of “firmness” in the beginning of consumption, which turned into a “melty” sensation for MFA15 while “graininess” and “brittleness”



**Fig. 5.** Principal component analysis (PCA) of the dominance duration for all yogurt samples for the evaluation of flavor. The PCA was performed on the standardized data. (a) Correlation plot of the observations on the average on all sips for each yogurt, an 80% confidence ellipse is drawn. (b) Plot of the variables (c) Correlation plot of the observations with the projection of the three yogurt spoons (A, B, C) for each yogurt sample.

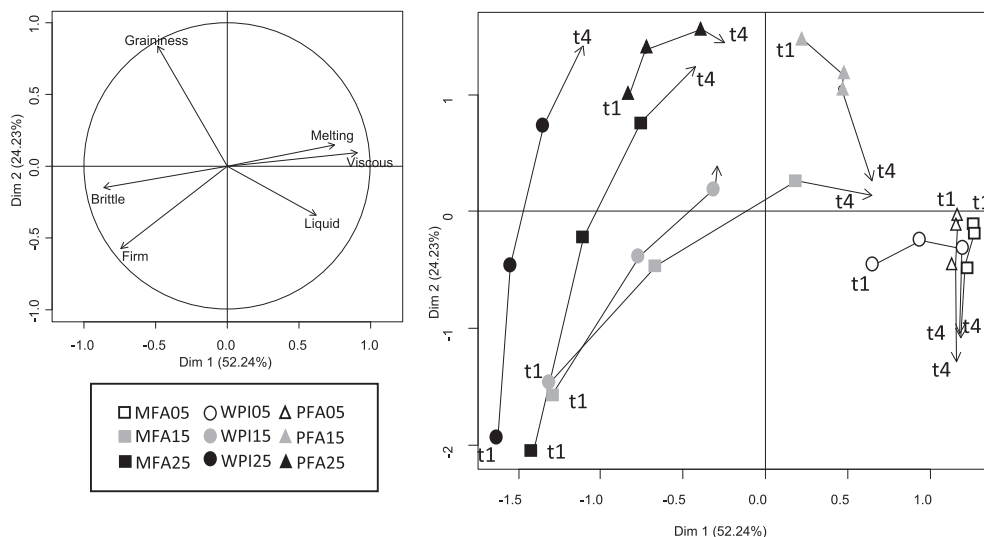
were dominant for WPI15.

**3.5.2. Flavor**

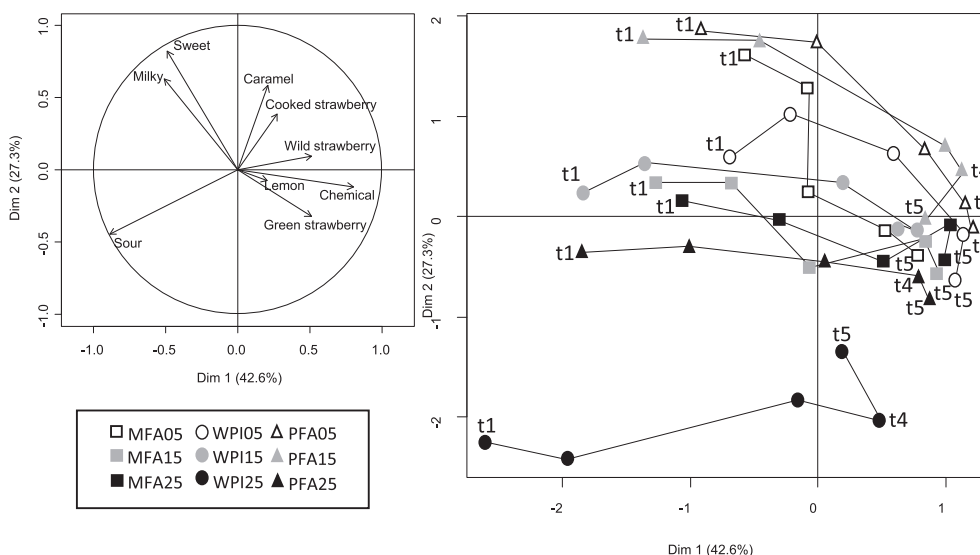
The same approach was performed for the attributes of flavor perception. The first two dimensions of the PCA of the sensory trajectories for flavor evaluation accounted for 72% of the variability observed among samples (Fig. 7). At the beginning of consumption, samples were differentiated according to the second dimension of the PCA, which was mainly related to sweetness. PFA15, PFA05 and MFA05 were the

samples for which sweetness was the most dominant sensation. Most interestingly, differences of sweetness were evidenced between yogurts enriched with different type of proteins at the same protein concentration. For instance, the dominance of sweetness was much higher in MFA25 and PFA25 than in WPI25.

All trajectories pointed in the same direction at the end of evaluation, which corresponded to the attributes related to the strawberry flavor. It is worth noticing that swallowing happened at the fourth point represented on the sensory trajectory. Therefore, the yogurt samples do



**Fig. 6.** Principal component analysis representing the texture trajectories of 9 yogurt samples over the consumption period. The PCA was performed on the standardized data.



**Fig. 7.** Principal component analysis representing the flavor trajectories of 9 yogurt samples over the consumption period. The PCA was performed on the standardized data.

not seem to be different regarding the aftertaste, which was represented in the last part of the trajectories. The attribute “chemical” appeared to be important to describe the aftertaste of the yogurts. WPI25 was the only sample clearly different from the others at the end of consumption, and it was almost exclusively characterized by a green strawberry flavor.

## 4. Discussion

### 4.1. Relevance of combining M-TDS and the multi-intake approach to study texture and flavor perception of semi-solid products

#### 4.1.1. Relevance of the multi-intake approach

In the present study, M-TDS methodology was performed using a multi intake approach to efficiently assess the perception of texture and flavor in a semi-solid product such as yogurt.

No significant impact of the number of spoons was seen for texture attributes, which is consistent with other results presented in the literature. Galmarini et al. (2017) performed multi-intake TDS and studied the bite effect on the dominance duration of attributes. They did not find a bite effect, except for the attribute sticky in only one cheese among the four cheeses evaluated. The same trend was also obtained by Thomas et al. (2017) on TDS with dynamic hedonic evaluation. This result was expected regarding texture evaluation as the texture descriptors chosen described in-mouth sensations which were unlikely to cumulate over spoons of yogurt.

Regarding taste and flavor, the number of spoons had an impact on sweetness and sourness perception, but there was no significant modification of the strawberry flavor attributes (Table 4). The dominance duration of sweetness and sourness was significantly lower at the 3rd spoon compared to the 1st one (Table 5). This evolution of perception can be attributed to sensory adaptation (Köster, Couronne, Léon, Lévy, & Marcelino, 2003) and might be interesting to take into account when considering the consumption of a whole yogurt. Zorn et al. (2014) performed a study on orange juices with different sweeteners, and also evidenced a modification of the perception of sweetness, sourness and bitterness with the number of sips. Moreover, there was no impact of the number of sips on the perception of orange flavor attributes, which corresponds to the results we got on the strawberry yogurts. Oliveira et al. (2015) performed a TCATA with a multi-sip protocol to evaluate the impact of sugar reduction in chocolate flavored milks. Again, they showed an impact of the sip on taste attributes such as sweetness,

sourness or bitterness, without any impact on chocolate flavor attribute. They also proved that the differences perceived between the chocolate flavored milks were not the same depending on the number of sips. The multi-intake approach appeared to be relevant mostly for the evaluation of taste attributes. Recording the perception of more than one spoon of yogurt gives a more complete view of the sensations experienced by consumers during the regular consumption of the product. The decrease of sweetness and sour dominance after three bites of yogurts suggested that the perception of taste varied during the consumption of the product and could impact consumers liking and acceptance. The multi-intake approach did not highlight aroma perception modifications. This result is consistent with the literature (Oliveira et al., 2015; Zorn et al., 2014). A hypothesis to explain it may be that taking only three spoons of yogurt in a row was not enough to influence aroma perception. In fact, Thomas, van der Stelt, Prokop, Lawlor, and Schlich (2016) studied the evolution of perceptions during the intake of the full portion of an oral nutritional supplement, and evidenced differences in aroma attribute “praline” along consumption. More differences of aroma perception may appear during the consumption of a whole portion of strawberry yogurt.

#### 4.1.2. Relevance of performing the TDS task by modality (M-TDS) by analyzing the non-standardized data.

Both the consumption time and the time before the first click on a descriptor were higher for flavor than for texture evaluation (Figs. 1 and 2). This difference reflected the different kinetics of the two class of attributes. Texture attributes were immediately perceived as the yogurt was put in the mouth, while the progressive release of taste and aroma compounds generated a delay time before flavor attributes could be perceived and evaluated. This is why the time needed to click on the first descriptor was more than doubled for flavor evaluation compared to texture for the firmest yogurts. We can also hypothesize that once the aroma compounds are released, several sensations caught the attention of the panelists. The complexity of the flavor evaluation might influence the consumption behavior of the panelists and induced them to keep the yogurt for a longer time in their mouth. The consumption behavior of panelists was influenced by the modality they were evaluating and appeared to be different from their real and natural consumption behavior. The only significant difference evidenced in the time needed to click on the first descriptor regarding texture evaluation was between WPI25 and the other samples (Fig. 2). We can hypothesize the attribute “firm” was perceived as soon as the sample was put in the mouth

because it did not require oral manipulation. On the contrary, the evaluation of the “viscous” attribute required more oral manipulation, which extended the time to click on the first descriptor.

These results highlighted that selecting the dominant attribute for texture and flavor was a complex task for assessors, especially regarding flavor evaluation. It is therefore relevant to study texture and flavor separately in order to obtain an in-depth characterization of products. These results are in line with those obtained by Meyners (2019) and Nguyen et al. (2018) and highlight the fact that M-TDS is particularly well adapted to evidence subtle differences of texture and flavor in semi-solid products.

#### 4.1.3. Relevance of performing M-TDS by analyzing the standardized data.

This approach was meant to retrieve the multisensory aspect of perception in a semi-solid product such as yogurt. The differences in texture perception were very clear among products, as shown by the very different sensory trajectories and the high consensus between judges revealed by the PCA (Figs. 6 and 7). On the contrary, the differences of flavor perception were subtler, especially regarding the aftertaste of the yogurts. These results confirmed our previous instrumental measurements, as significant and marked differences were evidenced regarding texture (Lesme et al., 2019). On the contrary, measurements of the release of aroma compounds in the headspace at thermodynamic equilibrium evidenced subtle variations of retention between the yogurts for some aroma compounds (results not showed). This trend confirmed previous results obtained in flavored yogurts with different protein content (Saint-Eve, Juteau, Atlan, Martin, & Souchon, 2006). In this context, evaluating the yogurts by modality appeared to be efficient to highlight the slight differences of flavor and taste perception (Fig. 7).

In our study, even by evaluating separately texture and flavor, the temporal profiles of yogurts were dominated by texture attributes, followed by taste attributes, whereas aroma attributes were not the main dominant characteristics. The same trend was observed by Galmarini et al. (2017) in a study on temporal profiles of cheeses. The samples were mostly characterized by texture and taste, whereas flavor attributes were not the main characteristics. Bemfeito, Rodrigues, Silva, & Abreu (2016) also studied sensory profiles of cheeses evaluating texture and flavor separately. The sensory profiles were dominated by texture attributes, taste attributes such as salty and bitter were also dominant, whereas the aromatic attributes reached very low dominance rates. Aromatic attributes might not be the most essential attributes for cheese acceptability. However, the perceived flavor of fat-free products is known to be dramatically changed, which makes the study of flavor perception essential to achieve a desirable and pleasant aroma in light dairy products (Kühn, Considine, & Singh, 2006). As a consequence, the separated evaluation of texture and flavor modalities appeared to be relevant and essential to obtain exploitable data regarding the temporal flavor profile of the strawberry yogurts. These results were in line with the study of Nguyen et al. (2018) performed on yogurts.

#### 4.2. A combination of statistical treatments to study texture and flavor perception

The comparison of the consumption durations among samples, obtained from the non-standardized data, gave indications on the texture of samples. The mean consumption durations were longer than 9.89 s, which is slightly higher than the results obtained by Mesurolle et al. (2013) on stirred yogurts (Fig. 1). This short time reflected the semi-solid texture of set yogurts which required little mastication.

As the modalities were evaluated separately, two curves of dominance rate were obtained for each yogurt. There was always more than one dominant attribute, and the sequence of dominant attributes could be compared from one product to another. The maximum dominance rate (0.78) was reached for texture attributes, showing a high consensus between assessors (Fig. 3(a)). As expected, the dominance rates for

texture attributes were higher than the dominance rates for flavor attributes. The fact that several flavor attributes were comprised between the chance and the significance level can be related to a higher difficulty for panelists to evaluate flavor (Fig. 3(b)). This difficulty might be due to the complexity of the strawberry flavor profile, with several sensations catching the attention of the panelists at the same time. This might be an interesting element as sensory complexity can be a positive feature for the acceptance of the product by consumers (Palczak, Blumenthal, Rogeaux, & Delarue, 2019). The dominance curves showed the sequence of dominant attributes at panel level and gave information on the consensus between subjects, but it was difficult to compare all the products, for texture and flavor, with this representation.

A PCA, based on the dominance duration, was performed on the results obtained from texture and flavor evaluations. Significant differences were observed between samples. It can be noted that a clear impact of the protein concentration was found for texture and flavor perception: the higher the protein concentration, the firmer and more brittle the yogurts. Viscous and melty yogurts (low protein concentration) were perceived with a higher dominance of strawberry flavor compared to firm yogurts (Fig. 4). The PCA also gave information on subtler differences between products. Significant texture differences were evidenced depending on the type of protein used: for the same protein concentration, MFA25, WPI25 and PFA25 did not have the same texture characteristics.

Moreover, the increase of protein concentration did not have the same impact on flavor perception depending on the protein type added in the yogurts. The impact of the protein concentration on the flavor profile was more important for yogurts enriched with WPI compared to yogurts enriched with MFA or PFA (Fig. 5). As shown in Bruzzone et al. (2013), the duration of dominance is an interesting parameter to discriminate yogurt samples. The removal of the temporal aspect of the data makes the comparison with a classical sensory profiling possible, but aspects linked to the temporality of the descriptors are lost (Di Monaco et al., 2014).

To be able to compare all the products together without losing the temporal dimension, the sensory trajectories were an efficient tool. Even for yogurt, which is a semi-solid product with almost no need of mastication, clear groups could be identified for texture perception (Fig. 6). Some attributes appeared only at certain time points: firmness, and brittleness only at the beginning of consumption. On the contrary, graininess was perceived either at the beginning of consumption or at the end. This information is important because the same sensation might have different origins. In our case, the “grainy” sensation perceived at the beginning of the evaluation period might be caused by the large WPA present in the PFA. On the other hand, the “grainy” sensation felt before swallowing was a consequence of the evolution of the texture of the yogurts that were very firm when put in mouth. The differences in flavor perception were closely linked to texture perception. At the beginning of evaluation, when the yogurts were not de-structured yet, clear differences were perceived between samples regarding taste and flavor attributes (Fig. 7). For instance, the impact of the type of protein on sweetness perception was striking: for the same protein concentration, PFA25 and MFA25 were perceived as being sweeter than WPI25. A lower sweetness intensity could result from a delay or partial inhibition of the transport of the taste compounds within the food matrix, or from the matrix to the taste receptor (Brossard, Lethuaut, Boelrijk, Mariette, & Genot, 2006). The impact of formulation on sweetness perception was mostly investigated in model dairy products containing different texturing agents such as starch or hydroxypropyl methylcellulose. These studies evidenced that the diffusion of tastant molecules was limited by the network formed above a threshold concentration of hydrocolloids. We can hypothesize that a parallel can be drawn with the yogurt protein network becoming denser as the protein concentration is increased, thus reducing the diffusion of sweet molecules. Moreover, the mixing behavior of the food matrix with saliva was also found to be a key parameter for taste perception

(Mosca, van de Velde, Bult, van Boekel, & Stieger, 2012). Yogurts enriched with MFA and PFA, which were more viscous, meltier and less brittle than yogurts enriched with WPI might mix more easily with saliva, enabling the taste components to be more released from the yogurts and to interact more efficiently with the corresponding receptors, thus increasing sweet perception

Flavor perceptions evolved along the evaluation period because of the loss of texture, which induced the release of flavor compounds in the mouth. The impact of texture on the evaluation of flavor was also seen when analyzing the time before the 1st click on a descriptor. Multiple comparison tests evidenced different groups of yogurts with WPI25 (firmest yogurt) with the longer time and PFA05 and PFA15 (most liquid and viscous yogurts) with the shorter time (Fig. 1). Having the texture and the flavor profiles of the same products evidenced the importance of the dynamic process of texture perception (continuous changes of physical characteristics) and its impact on flavor perception through consumption. A large part of flavor evaluation included the aftertaste description, which did not depend on texture anymore. This step was much more complex for assessors, and even if there were some dominant attributes, no significant differences were evidenced between samples. As underlined by several studies, the representation of sensory trajectories brought crucial additional information compared to the PCA on dominance duration (Lenfant et al., 2009; Schlich, 2017).

The combination of all these statistical treatments on the data obtained by TDS gave complementary information useful to truly characterize the differences between yogurt samples that will most certainly enable a more efficient formulation of fat free dairy products.

## 5. Conclusions and perspectives

The study of texture and flavor in semi-solid products is complex because of the rapid changes happening during the short consumption time.

The evaluation by modality and with a multi-intake approach was useful to highlight the subtle differences of flavor between the fat-free strawberry yogurt samples. As the differences of texture were more evident than the flavor ones, the evaluation by modality was particularly relevant to obtain exploitable data regarding flavor perception. It enabled a thorough characterization of semi-solid products, taking into account the more evident texture differences as well as the subtler flavor variations. The multi-intake approach showed that the evaluation of the samples varied depending on the number of spoons. This difference was mostly due to changes in the perception of taste attributes, and it seems important to take it into account when studying flavor perception.

This study also underlined the importance of analyzing both standardized and non-standardized data. Moreover, working on dominance duration can provide rich information which is easier to interpret than the TDS curves, and complemented data analysis focused on temporality. By combining these approaches, the results obtained were precise enough to evidence differences between products and to make links between texture and flavor perception. For instance, this adapted TDS methodology not only evidenced that the addition of WPA in fat-free strawberry yogurts led to texture modifications, but also that it induced changes in the perception of sweetness.

This study provides a methodology to discriminate samples enriched with different whey protein aggregates, which is particularly valuable, as clear distinctions between samples produced using similar ingredients can be difficult to evidence instrumentally. These results can most certainly have implications in the development of fat-free dairy products, with an approach valid for semi-solid products in general.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodqual.2019.103789>.

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