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Dynamic texture perception in plant-based yogurt alternatives: Identifying temporal drivers of liking by TDS

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ABSTRACT

As texture properties in novel food categories have a crucial role in consumer acceptance, mouthfeel profile of different plant-based yogurt-like semi-solid products were studied and compared to dairy yogurts. Mouthfeel properties of five plant-based yogurt-like products and two dairy yogurts were analyzed using temporal dominance of sensations (TDS) with consumers (n = 87). The attributes evaluated were thick, thin, creamy, watery, sticky, and foamy. Following TDS, overall liking and mouthfeel liking were evaluated using a 7-point hedonic scale. Temporal drivers of mouthfeel liking were studied using correspondence analysis and penalty-lift analysis with different time points during mastication. For penalty-lift analysis TDS data was analyzed as check-all-that-apply (CATA) data. Results from the present work show that mouthfeel perception in non-dairy yogurt alternatives is a dynamic process. Attributes typically used to describe dairy yogurts are also relevant for describing non-dairy yogurt alternatives. Yogurt alternatives and dairy yogurts can be similar and equally liked by their mouthfeel profile. Temporal drivers of liking in plant-based products are thickness and creaminess and temporal drivers of disliking are thinness and wateriness. In this study, the first dominant attributes were found to have a stronger impact on mouthfeel liking than the dominant attributes perceived later during mastication.

1. Introduction

Consumer demand for cow's milk alternatives has increased due to the constantly increasing awareness on sustainable food production as well as medical reasons such as lactose intolerance and milk allergies. Especially in western countries, the market is developing rapidly as plant-based alternatives are gaining popularity. They can offer a sustainable option especially when formulated into nutritionally adequate and palatable products (Mäkinen, Wanhalinna, Zannini, & Arendt, 2016). A good example of these are fermented plant-based semi-solid yogurt alternatives which have recently challenged dairy-based yogurts. Consumer attitudes towards new products have previously been studied by using specific innovativeness scale (DSI) (Goldsmith & Hofacker, 1991; Huotilainen, Pirttilä-Backman, & Tuorila, 2006; Urala, Lähteenmäki, Huotilainen, Tuorila, Ollila, Hautala, & Tuomi-Nurmi, 2005), which has been shown to predict willingness to try and use new foods (Huotilainen, Pirttilä-Backman, & Tuorila, 2006).

Oat (*Avena sativa L.*) is primarily a cool climate crop. Northern countries like Canada, Finland and Sweden have a long tradition of using oat in a variety of foods. Oat is nowadays highly accepted by the consumers (Banovic, Arvola, Pennanen, Duta, Brückner-Gühmann, Lähteenmäki, & Grunert, 2018; Brückner-Gühmann, Banovic, & Drusch, 2019). Compared to other cereal grains, oat is perceived to have greater health benefits, aiding to its positive image among consumers (Banovic, Arvola, Pennanen, Duta, Brückner-Gühmann, Lähteenmäki, & Grunert, 2018). Food and Drug Administration (FDA) and European Union (EU) have authorized health claims for oat's beta-glucan on lowering blood cholesterol level and improving blood sugar management (EFSA, 2010; FDA, 1997). There is recent evidence that lactic acid fermented, oat-based gel is a good carrier for oat protein enrichment and that oat proteins with the help of carbohydrates contribute to desirable overall mouthfeel properties (Brückner-Gühmann, Banovic, & Drusch, 2019).

In order to meet consumer acceptance, production of plant-based products requires thorough control of the texture attributes. Particularly, texture and mouthfeel play an important role in overall acceptability of food and may even cause food aversions (Ares, 2011; Pohjanheimo & Sandell, 2009; Scott & Downey, 2007). Texture perception of semi-solid food gels is a dynamic process as the structure of

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Table 1
Macro-components, protein source, starch and stabilizers in the evaluated yogurt-type products.

	Fat g/100ml	Carboh. g/100ml	Sugar g/100ml	Fiber g/100ml	Proteins g/100ml	Oat content, %	Salt g/100ml	Protein source	Starch / Pectin	Thickening agent / stabilizer
D1	2.5	4.1	4.1	0.0	4.2	0.0	0.1	milk protein		
D2	4.0	4.1	4.1	0.0	4.0	0.0	0.1	milk protein		
P1	2.2	9.9	4.6	1.3	1.7	12	0.07	oat base (water, oat 12%, culture), potato protein	potato starch	calsium carbonate (E170), tricalcium phosphate (E341)
P2	2.4	11.1	5.2	1.0	0.8	8.5	0.12	oat base (water, oat 8.5%)	modified starch, pectin	potassium Sorbate (E202)
P3	2.5	9.2	4.8	na*	1.0	8.0	0.08	oat base (water, oat flakes 8%)	starch (corn, potato), pectin	tricalcium phosphate
P4	0.8	8.2	2.3	0.0	2.2	8.3	0.09	water, oat 12%, potato protein	tapioca starch, potato starch	xanthan, locust bean gum
P5	1.9	12	2.5	0.13	2.1	12	0.06	oat base (water, oat), pea protein	modified potato starch	

*na = not available.

food alters during mastication due to oral processing and chemical breakdown in mouth (Devezeaux de Lavergne, Van De Velde, Van Boekel, and Stieger, 2015a; Hutchings & Lillford, 1988). Understanding the dynamic sensory perception is essential in order to explain eating behaviour, acceptance and linking of food products (Chen, 2014; Koç, Vinyard, Essick, & Foegeding, 2013). Previous literature on mouthfeel properties of semi-solid food has focused on dairy yogurts (Nguyen, Næs, & Varela, 2018), soybean and dairy custards (Engelen, de Wijk, Prinz, van der Bilt, & Bosman, 2003), vanilla custards (de Wijk, Engelen, & Prinz, 2003), and different emulsion filled gels (Devezeaux de Lavergne et al., 2015a). The scientific attention is still limited for plant-based yogurt alternatives.

de Wijk, Prinz, and Janssen (2006a) indicate that each sensory dimension has attributes that are either related to surface properties or bulk properties of the food bolus. Nguyen, Næs, and Varela (2018) demonstrated that the initial dominant perception was related to the viscosity properties. As for the chronology of the attributes during mastication, it has been indicated that sensations of those bulk-dominated texture features were detected relatively quickly, whereas sensations related to surface properties were detected more slowly (Chen & Stokes, 2012; de Wijk, Janssen, & Prinz, 2011). In dairy yogurts, thickness, creaminess and smoothness have been previously linked to liking (Bayarri, Carbonell, Barrios, & Costell, 2010; Pohjanheimo & Sandell, 2009). Brückner-Gühmann, Banovic, and Drusch (2019) studied the drivers of liking in oat-based gels and concluded that attributes like sweet, moist, soft, and smooth influenced product acceptance. However, research on the influence of changes in the sensory characteristics of samples during mastication on liking is still limited (Sudre, Pineau, Loret, & Martin, 2012).

As texture is a multidimensional sensory property (Szczesniak, 2002), temporal methods such as temporal dominance of sensations (TDS) give valuable information on texture profiles for new product categories. TDS is a sensory method that studies the sequence of dominant sensations of a product during a certain time period (Meyners & Pineau, 2010; Meyners, 2011). It focuses on the determination of the most "dominant" sensation over time (Pineau, Schlich, Cordelle, Mathonnière, Issanchou, Imbert, & Köster, 2009) or the sensation that catches the most attention at a time point during mastication. Meyners (2016) and Ares, Alcaire, Antúnez, Vidal, Giménez, and Castura (2017) studied temporal drivers of liking using TDS by considering the TDS data as choose-all-that-apply (CATA) data and using penalty-lift analysis, as proposed by Meyners (2016).

To be able to successfully develop plant-based food products, the industry needs reliable information on the dynamic mouthfeel profile and information on the drivers of liking in such products. In this context, we concentrate on the dynamic mouthfeel profile of this novel food category, semi-solid plant-based yogurt alternatives. The aim was to determine how mouthfeel perception alters during mastication and to understand if there is a difference in temporal texture profile between plant-based and dairy yogurts by using temporal dominance of sensations (TDS) in a consumer test. The second aim was to identify the temporal drivers of mouthfeel liking and disliking in the plant-based semi-solid yogurt alternatives and specially to understand to what extent the bulk properties are responsible for liking. We hypothesize that mouthfeel perception in plant-based yogurt alternatives alters the same way as in dairy yogurts and that the first perceived mouthfeel properties during the mastication are the key drivers of liking in semi-solid plant-based food.

2. Material and methods

2.1. Samples

The samples were five unflavored plant-based yogurt alternatives (P1-P5) and two dairy yogurts (fat content 2.5% and 4%) (D1-D2) which served as references. The non-dairy products were yogurt-like semi-solid spoonable snacks containing oat as a key protein source. These yogurt alternatives were selected due to their different structure and they represent the variety of oat-based yogurt alternatives in the market. The two dairy yogurts represent common dairy yogurts in Finland. They were included as reference samples because of the abundance of related literature on dairy yogurts. All the products were commercial and purchased from supermarkets in Southern Finland. The products varied by the content of macro-components. In plant-based products, protein content varied from 8 to 12 g/100 ml and fat content from 0.8 to 2.5 g/100 ml (Table 1). Proteins in the products are mainly from oat, apart from P4 and P5 which contain also potato protein (P4) and pea protein (P5). All the products are fermented, and contain starch from potato, corn or tapioca. Two of the products (P2 and P3) contain pectin.

2.2. Development of vocabulary

To aid the development of vocabulary for TDS five different commercial non-dairy yogurt alternatives were characterized with General Descriptive Analysis (GDA) by an expert panel (n = 12) at Valio R&D. First the vocabulary and evaluation techniques were agreed on by the panel. The evaluation was repeated on three different days so that 12 panelists took part in the first session and 10 panelists took part in the second and third session. Descriptors reported by the panel were runny and pudding-like texture (both by spoon), stickiness and thickness (both in mouth). Sweetness and sourness were evaluated to get an overview of the taste differences between the products. Only texture attributes evaluated in the mouth were selected for the TDS. Attributes thick, creamy, thin, watery, sticky and foamy were chosen to be used in TDS method according to the GDA and previous literature.

2.3. Sensory evaluation

2.3.1. Participants

A total of 87 consumers took part in the sensory evaluation (Table 2). The study was conducted in the sensory laboratory at the University of Helsinki, Department of Food and Nutrition, Finland. The participants were recruited from the university campus area, Viikki, Finland. The respondents signed an informed consent form before entering the study. The research procedure followed the ethical principles of sensory evaluation laboratory, approved by the Ethical Committee of the University of Helsinki. Before the evaluations, participants were informed that the samples would be fermented dairy and oat-based spoonable snacks. Anyone over 18 years old and without restrictions related to milk, lactose, or oat was eligible to participate in the study. Majority of the participants (68%) were either students or staff members from the Faculty of Agriculture and Forestry.

2.3.2. Procedure

For the time dependent method, TDS, conducted by consumer test, all panelists received attribute definitions and verbal instructions of the procedure. They were instructed to evaluate the texture and mouthfeel properties of the samples and to select the term that caught their attention at each moment of the evaluation (Pineau, Schlich, Cordelle, Mathonnière, Issanchou, Imbert, & Köster, 2009). They were instructed to consume the sample at least 5 s and no more than 40 s. In order to familiarize consumers with the TDS method, a warm-up session with same six attributes and berry jelly was organized.

Table 2
Panel demographics, n = 87.

		n	%
Sex	Female	76	87.5
	Male	10	11.5
	N/A	1	1.1
Age	20–29	55	63.2
	30–39	16	18.4
	40–49	10	11.5
	50–59	6	6.9

Each panelist was presented a 40 g of the sample in a 75 ml plastic cup. Serving temperature of the samples was 10 °C. The samples were coded with a three-digit number and their order was randomized for each assessor (latin square). Evaluation was carried out under red light to minimize the color differences between the products. The panelists did not know whether they were evaluating plant or dairy-based yogurts. Evaluations were conducted in individual booths with FIZZ Sensory Evaluation Software, Version 2.45 (Biosystemes, Courternon, France). Panelists were instructed to cleanse their palates with tap water and unflavored corn snacks between the samples.

2.3.3. Questionnaire

After the dynamic characterization of each sample, consumers were asked to re-taste the samples and to rate their overall liking and mouthfeel liking using a 7-point hedonic scale (1 = dislike very much, 7 = like very much). Demographic related questions (sex, age, food or nutrition related work or studies) were asked after the tasting procedure. In addition to demographics, a domain specific innovativeness (DSI) scale (Goldsmith & Hofacker, 1991; Huotilainen, Pirttilä-Backman, & Tuorila, 2006; Urala, Lähteenmäki, Huotilainen, Tuorila, Ollila, Hautala, & Tuomi-Nurmi, 2005) with six questions (Table A1) on attitudes and willingness to purchase plant-based yogurt alternatives was used to gain understanding on consumer's attitudes towards plant-based products. The questions were rated on a 7-point scale from 'strongly disagree' to 'strongly agree'.

2.4. Statistical analysis

TDS curves, correspondence analyses and penalty-lift analyses were carried out using XLSTAT-Sensory software (version 2019.3.22019; Addinsoft, France). Principal component analysis (PCA) was run by software program The Unscramble (version X 10.5.1, Norway). All other data analyses were carried out using IBM SPSS Statistics software (version 25, USA). Statistically significant results at $p < 0.05$ are reported.

With the DSI, a split into three groups was made for forming innovator groups from the questionnaire. By using 33rd and 66th percentile as cut-off points the respondents were placed in either Laggards (n = 27), Moderates (n = 29) or Innovators (n = 31) as Huotilainen, Pirttilä-Backman, and Tuorila (2006) proposed. The Cronbach's alpha for the DSI scale was 0.879 which indicates that the scale can be considered as reliable (Goldsmith & Hofacker, 1991; Huotilainen, Pirttilä-Backman, & Tuorila, 2006).

2.4.1. TDS curves and parameters

For descriptive purposes, TDS curves were obtained by plotting the dominance rates of each of the sensations at different time points of the eating period (Pineau, Schlich, Cordelle, Mathonnière, Issanchou, Imbert, & Köster, 2009). For the figures, the data from each subject was standardized across the whole mastication period. Dominance rates were smoothened before plotting them against the time period. Chance level, p_0 as proposed by Labbe, Schlich, Pineau, Gilbert, and Martin (2009), equals to 1/p, p being the number of attributes (here 6). Significance level, p_s was calculated using a binomial test to achieve the minimum value dominance rate to be significantly higher than chance level (Pineau, Schlich, Cordelle, Mathonnière, Issanchou, Imbert, & Köster, 2009). Three TDS parameters were calculated from the data. The area under the TDS curve and above the significance level (AUC) and maximum value on Y axis which corresponds to a dominance rate (maxDR) were calculated from the standardized TDS data. The attribute duration (AD) which is the duration period for each selected attribute for each product were calculated from the non-standardized raw data.

One-way ANOVA followed by Tukey's test was used to calculate the differences in AD-values between different descriptors. Principal component analysis was carried out to visualize the correlations between the attributes, and areas under the curve and maximum dominance rates. The samples were added in PCA to understand their relative properties.

2.4.2. Temporal drivers of liking

Overall liking and mouthfeel liking scores were analyzed using one-way ANOVA with product as fixed factor. Tukey's HSD test was used for pairwise comparison between the products among all consumers. Unpaired *t*-test was used between Laggards and Innovators to compare means of overall liking and mouthfeel liking.

To understand the drivers of mouthfeel liking in all the products, a correspondence analysis (CA) was conducted. For CA, TDS data was considered as check-all-that-apply (CATA) data, as indicated by Meyners and Castura (2014). This was done by aggregating responses over a specific time period (Ares, Alcaire, Antúnez, Vidal, Giménez, & Castura, 2017; Meyners, 2016). In this case the mastication period was divided into four equal (10 s) time period, Q1-Q4: 1–10 s (Q1), 11–20 s (Q2), 21–30 s (Q3) and 31–40 s (Q4). If the specific attribute was selected at least one time during the time period, it was considered as 1 and if it was not selected at all during the time period, it was considered as 0. This was done separately for each assessor. To demonstrate the drivers of mouthfeel liking, the mouthfeel liking was added for the CA as a supplementary quantitative data.

To quantify the key temporal drivers of mouthfeel liking, penalty-lift analysis was conducted for plant-based and dairy yogurts separately. As Meyners (2016) suggests, penalty-lift analysis can provide additional information to better understand the data. Average mouthfeel liking scores were calculated considering consumers and samples for which the attribute was selected and for which the attribute was not selected. The significance of the difference between these two liking score averages was calculated by unpaired *t*-test (Meyners, Castura, & Carr, 2013). According to the results of CA with four time periods (Q1-Q4) and after a careful review of the eating durations among the assessors, only the first 25 s was taken into account in the penalty-lift analysis. The first 25 s was split into five equal (5 s) time period, T1-T5: 1–5 s (T1), 6–10 s (T2), 11–15 s (T3), 16–20 s (T4), and 21–25 s (T5).

3. Results

3.1. Temporal mouthfeel perception

TDS revealed differences between creaminess, thickness, thinness, and wateriness (Fig. 1). In the two dairy yogurts, thickness and creaminess were the only significantly dominant attributes. Two of the oat products (P2 and P3) showed similar pattern in thickness and creaminess as the dairy yogurts. In three other oat products (P1, P4 and P5) thickness, creaminess, thinness, and wateriness were dominant during mastication.

For most of the samples, wateriness and creaminess increased during the mastication. Thickness and thinness showed slightly decreasing and more stable pattern during mastication. Each attribute was partly overlapping with each other. Creaminess became dominant after thickness and remained significant until the end of mastication in some of the products (D1, D2, P2 and P3) as seen in Fig. 1. Whereas thickness, wateriness, and thinness showed more time specific dominance. The attributes watery and thin were dominant at different time points for the various samples, but more often was reported at the end of mastication. Also, attributes sticky and foamy were reported in products P2 and P3, respectively, in the middle of mastication (Figs. 1 and 2), yet no significant dominance was found with these two attributes.

Durations for each attribute averaged across subjects using non-standardized data (Fig. 2) corresponds to the difference between the first click on the attribute and click of the following one. These results indicate the temporal profile of texture descriptors but it does not reveal the order of them. The results in duration periods show differences between the products in foaminess and stickiness even though these attributes were not significant by their dominance rates as seen in Fig. 1.

The two principal components account for 69.6% and 14.0% of the variance, respectively, (83.6% in total). Fig. 3 shows how the wateriness and thinness correlate with each other as well as attributes creamy and thick with each other. The figure also reveals differences between the relative properties of the products as the first component separates them into three groups where group 1 resembles products D1, D2, P2, P3, group 2 products P4 and P5 and group 3 product P1. By this separation, group 1 is associated more with thickness, creaminess, and foaminess, group 2 with wateriness and group 3 with thinness. Attribute stickiness does not correlate strongly with any of the attributes. However according to PCA, foamy is associated somewhat strongly with P3. The figure also reveals the correlation between maximum dominance rate and area under curve.

3.2. Temporal drivers of liking

There were differences among products in overall liking [$F(6, 602) = 4.56$; $p \leq 0.001$] and in mouthfeel liking [$F(6, 602) = 4.92$; $p \leq 0.001$)] (Table 3). The dairy products were significantly more liked than the plant-based yogurt alternatives and Tukey's HDS post hoc test showed similarities in the two dairy products in overall liking and mouthfeel liking. One of the oat products (P3) was as liked as the dairy product D2 by its mouthfeel properties. Furthermore, there was more variability in the liking scores of plant-based products compared to dairy yogurts.

When analyzing the liking scores among the dairy and plant-based products separately between the Laggards and Innovators, there was a significant difference between the two groups in overall liking [$t(288) = -2.541$; $p = 0.012$] and in mouthfeel-liking [$t(288) = -2.284$; $p = 0.023$], for Laggards: 3.1 ($\pm$ 1.7) and 4.0 ($\pm$ 1.7) and for Innovators 3.6 ($\pm$ 1.8) and 4.5 ($\pm$ 1.7), respectively. No difference was found in dairy yogurts.

Results from the correspondence analysis based on the aggregated TDS data over four identical periods of time (Q1-Q4) for five plant-based products and two reference dairy samples are presented in Fig. 4. Product P2 was more similar with product D2 than with product P3. P1 is markedly different from the rest of the products due to the dominance of the term watery and thin. Also, the CA shows similarities with P4 and P5.

Penalty-lift analyses based on the mouthfeel liking and aggregated TDS data over 25 s and in five different time periods (Fig. 5) shows that thickness and creaminess from the first 5 s until 15 s of the eating time associates positively with mouthfeel liking. On the other hand, thinness associates negatively with mouthfeel liking. No other time intervals or descriptors showed significant associations with the mouthfeel liking.

4. Discussion

The mouthfeel descriptors in this study were similar with previous experiments on semi-solid foods (Devezeaux de Lavergne, van Delft, van de Velde, van Boekel, & Stieger, 2015b; de Wijk, van Gemert, Terpstra, & Wilkinson, 2003; Engelen, de Wijk, Prinz, van der Bilt, & Bosman, 2003; Nguyen, Næs, & Varela, 2018). Previous studies used three types of descriptors for mouthfeel characterization including: either related to viscosity (thick, thin, moist, and melting), particle size (sandy, gritty, smooth) or more complex mouthfeel sensations (creamy, airy, elastic, and sticky). In this study, no descriptors related to particle size were used, as they did not describe the samples. This indicates the similarities of the products in that specific mouthfeel dimension: no product was found to be particularly grainy or granular while the vocabulary was developed by GDA. However, as in previous experiments

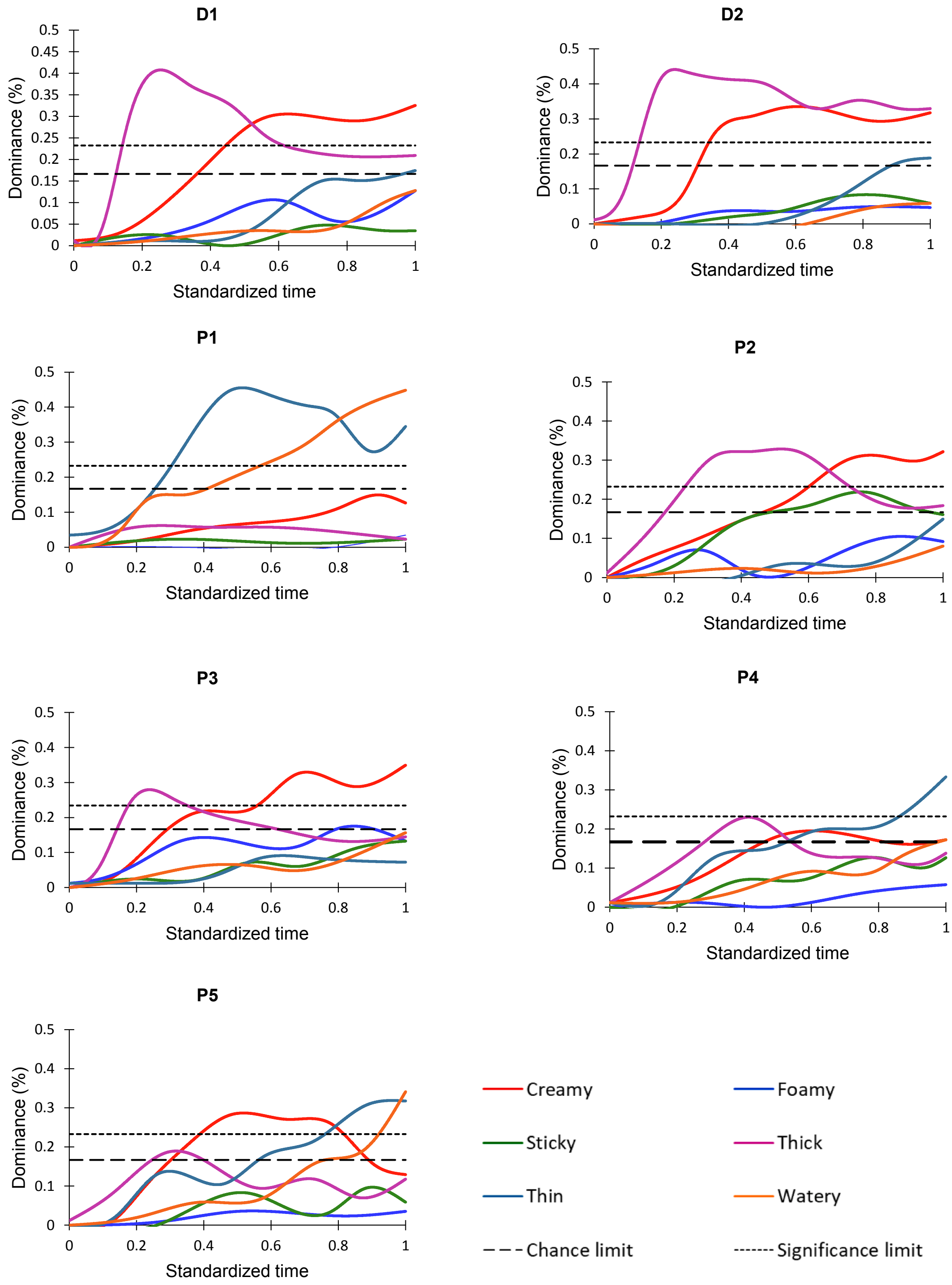

Fig. 1. Dominance rates of each 6 attribute for each product (D1-D2, P1-P5) plotted by standardized time with chance and significance levels, n = 87.

with semi-solid products, the descriptors used in this study were related to either viscosity and bulk properties (thick, thin, or watery) or more complex mouthfeel sensations (foamy) and surface properties (sticky and creamy).

4.1. Temporal mouthfeel perception

In the majority of the products, specific attributes appeared to be time dependent, differing at the beginning, in the middle and at the end of mastication. In all the products, excluding one plant-based product (P1), thickness was the first dominant attribute during mastication. Similar results were observed by Devezeaux de Lavergne et al. (2015b), reporting that thickness was the first attribute to be nominated in emulsion filled gels containing agar, gelatin, sunflower oil, water and sugar in different ratios. Also, Chen and Stokes (2012) and de Wijk, Janssen, and Prinz (2011) reported that bulk-dominated texture features are detected relatively quickly in semi-solid foods. These results differ from prior work, with Devezeaux de Lavergne et al. (2015b) reporting that descriptors elasticity and stickiness dominated the first 10 s of mastication, which could be due to the heterogeneity among the

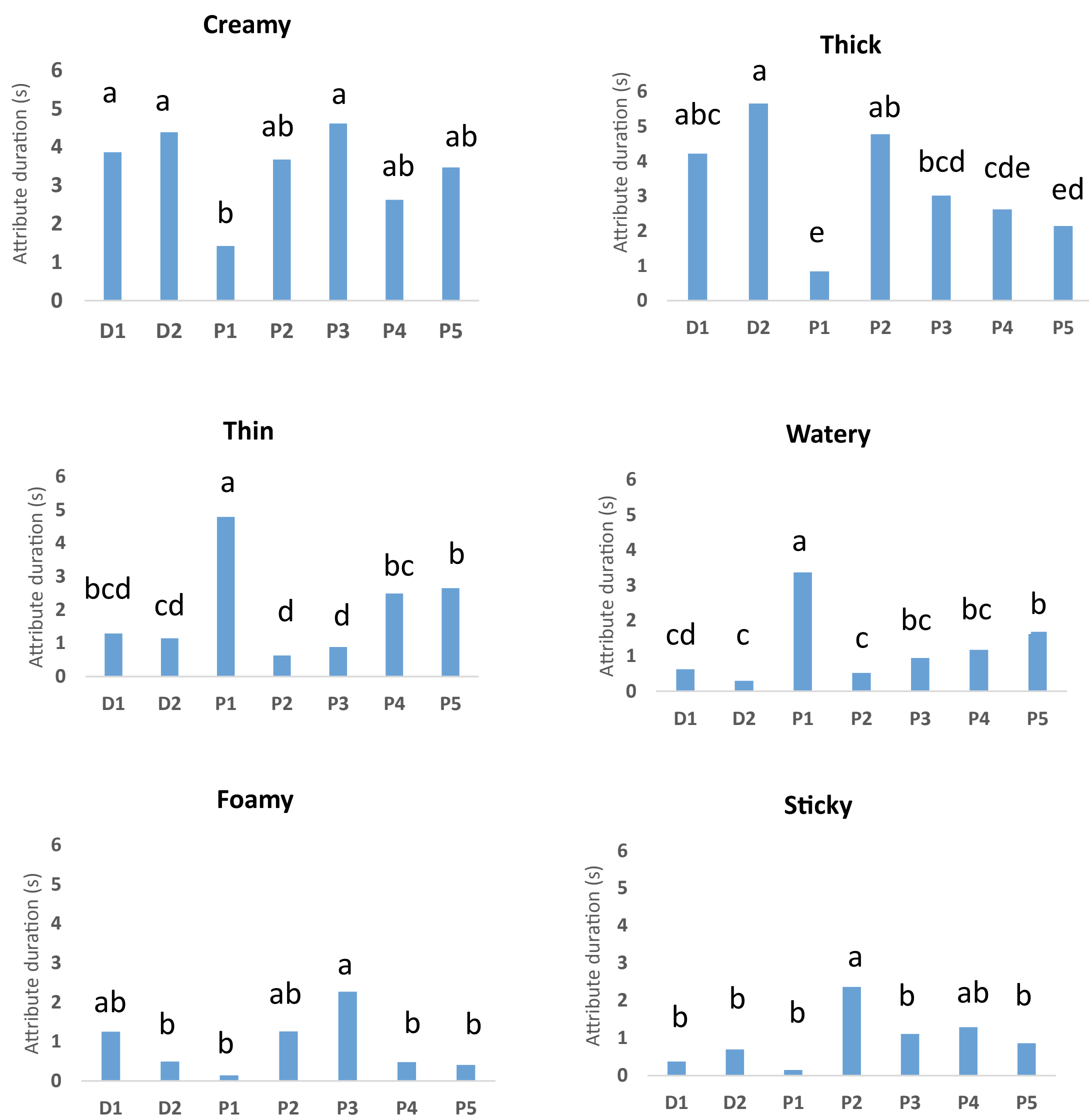

Fig. 2. Attribute duration (in seconds) averaged across subjects (n = 87) using non-standardized data. Different letters indicate significantly different ($p < 0.05$) groups by Tukey's test.

semi-solid texture.

The results demonstrate how the perception of mouthfeel is a dynamic process in both type of products. Yet, there is more variation among perceived attributes in plant-based products. The results support previous published results how the greater variation is observed in the mouthfeel sensations in the middle or at the end of mastication when the sample has been broken down by mixture of saliva and mastication. This is supported by Engelen, de Wijk, Prinz, van der Bilt, and Bosman (2003) as they discovered that viscosity reduces in custards 10 s after the saliva is mixed with the stimulus. This indicates that the reduction in viscosity occurs over time and is relevant to oral processing.

Primary focus of this study was to compare mouthfeel attributes between dairy and plant-based yogurts. Overall, dairy products showed lower dominant attributes than plant-based products. Dairy yogurts remained higher in the dominance of creamy until the end of mastication while thinness and wateriness dominated in the plant-based products. These differences could be due fracture properties and lack of relevant enzymes in mouth to hydrolyze the protein (Devezeaux de Lavergne et al., 2015a). However, more work is needed to understand the differences in physical properties between these two product types.

Two of the plant-based products (P2 and P3) showed greater similarity with the dairy products than with other plant-based products as thickness and creaminess dominated in their mouthfeel profile. This could be due them having the highest fat content among the plant-based products (2.4–2.5 g/100 ml). In dairy-based products, creaminess has been found to be correlated with fat content (Arancibia, Castro, Jublot, Costell, & Bayarri, 2015). Yet, there may be other factors that impact creaminess, such as the type of fat used in the product. de Wijk, Polet, Bult, and Prinz (2008) demonstrated that creaminess does not correlate with binding of oil to the gel matrix nor oil content released from the bolus during mastication. It has been suggested that alternative structural components (such as starch particles, protein aggregates, hydrocolloids) could contribute to smoothness and thickness which in other studies correlates with creaminess (Kokini, Poole, Mason, Miller, & Stier, 1984). Particularly, starches and their derivatives as thickening agents have been found to enhance creaminess perception (Eliasson, 2004). It should be noted that the two plant-based products resembling dairy yogurts contain pectin.

One of the oat products (P1) was evaluated as the thinnest and wateriest product which may be due to its high fiber content and addition of potato starch. de Wijk, Prinz, and Engelen (2004) demonstrated how semi-solid food is perceived as 'thinner' or 'melting in the mouth' as a consequence of being thickened with starch. This could be due to the hydrolysis of starch in the oral cavity by α-amylase present in

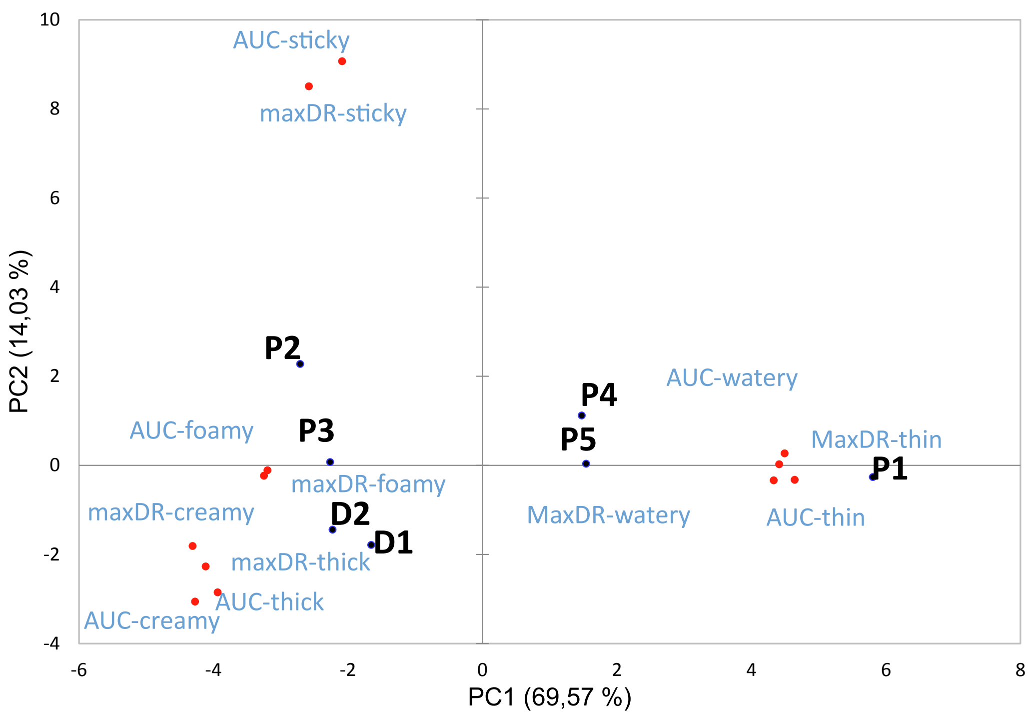

Fig. 3. Principal component analysis of the five plant-based products (P1-P5) and reference samples (D1-D2) and different TDS parameters of each of the descriptors. AUC corresponds to the area under the TDS curve and above the significance level and maxDR corresponds to the maximum dominance rate. AUC and maxDR were calculated from the.

Table 3
The means and standard deviations in overall liking and mouthfeel pleasantness for each product individually. Different letters within each column indicate the significantly different ($p < 0.05$) products by Tukey's HSD post hoc test, n = 87.

Products	Overall liking			Mouthfeel liking		
D1	5.2	± 1.4	a	5.6	± 1.2	ab
D2	5.7	± 1.4	a	6	± 1.2	a
P1	2.4	± 1.3	c	3	± 1.6	d
P2	3.8	± 1.8	b	4.6	± 1.8	c
P3	3.7	± 1.8	b	4.9	± 1.7	bc
P4	3.3	± 1.6	b	4.3	± 1.5	c
P5	3.3	± 1.7	b	4.4	± 1.5	c

saliva. The influence of enzymatic structural breakdown on creaminess perception has been demonstrated in experiments with starch-based custards containing additional α-amylase or an enzyme inhibitor (de Wijk, Prinz, & Janssen, 2006b). This is in line with our results, on how the creamy sensation in plant-based products does not necessarily last until the end of mastication (P4 and P5). Alternatively, previous studies have stated that creamy mouthfeel sensations increase over time for gels (Dickinson, 2018).

4.2. Temporal drivers of liking

Dairy yogurts were more liked than the plant-based products, which might be due to other sensory modalities like taste and appearance and the familiarity of dairy yogurts. This is supported by the fact that there was a significant difference in the overall liking between the two products (D2, P3), yet they were similar by their mouthfeel properties.

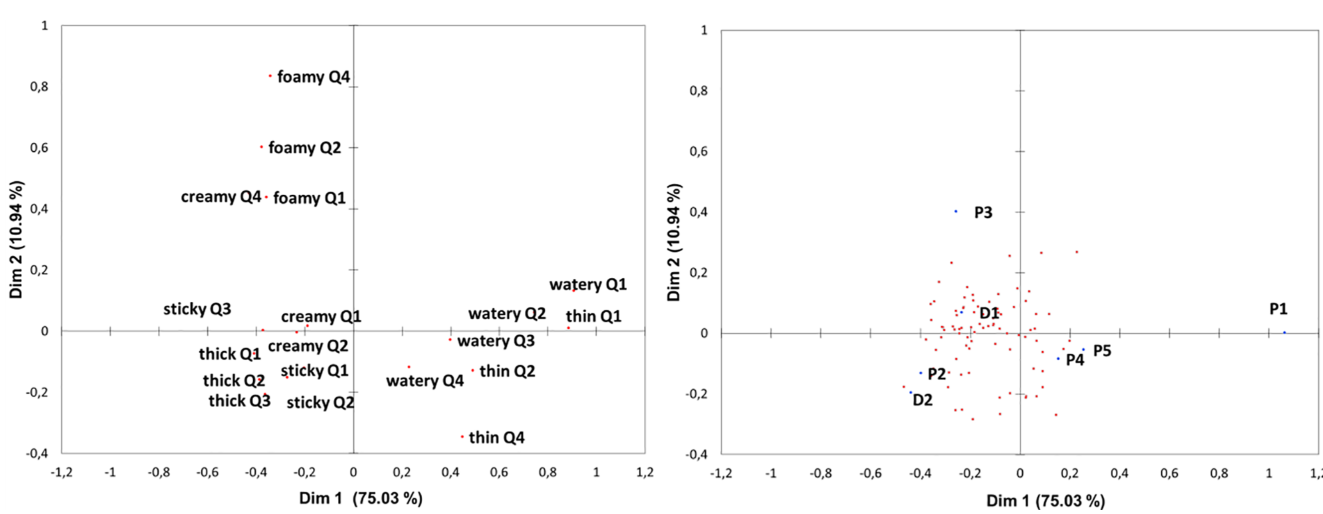

Fig. 4. Correspondence analysis based on aggregated TDS data in a CATA format for four identically long time periods (Q1-Q4) (A). The map shows the products projected into the area (B). Also, mouthfeel liking scores among consumers are projected into the same map as a complementary data, n = 87. The figure does not present all the time intervals because the analysis was only performed if the sample size (attribute selection among the panel) was greater than 20%.

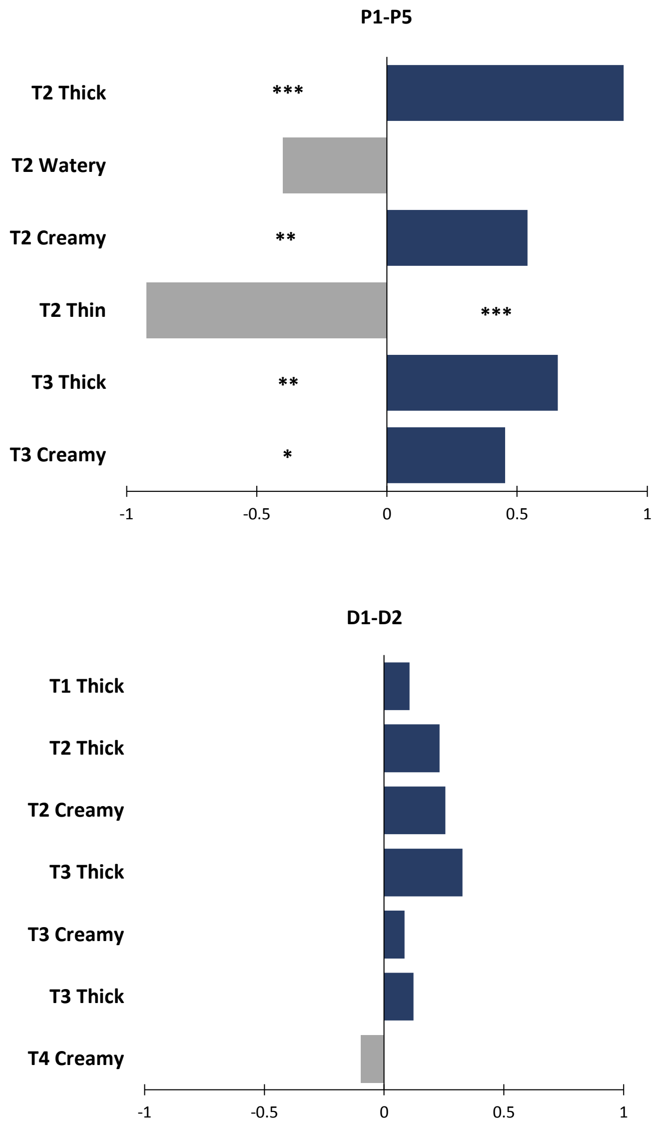

Fig. 5. Penalty-lift analysis of all the plant-based products (A) and dairy yogurts (B) in five different time intervals T1 = 1–5 s, T2 = 6–10 s, T3 = 11–15 s, T4 = 16–20 s, and T5 = 21–25 s. Dark blue bars indicate the significant positive drivers of mouthfeel liking and grey bars indicate the significant negative drivers of liking. Stars indicate significant mean drops (* $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$), n = 87. The figure does not present all the time intervals because the analysis was only performed if the sample size (attribute selection among the panel) was greater than 20%. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Thickness and creaminess have been previously studied as drivers of liking in dairy yogurts (Bayarri, Carbonell, Barrios, & Costell, 2010). The results suggest that these attributes are not just connected with dairy yogurts but also yogurt alternatives. In plant-based products the key drivers of liking and disliking are very similar compared to dairy yogurts. As shown by Brückner-Gühmann, Banovic, and Drusch (2019) the sensory attribute creamy increases the overall liking of the products, while other attributes – sour, chalky and floury – decrease the overall liking of the products. In dairy yogurts, no attribute was found to be a significant key driver by penalty lift analyses. However, according to TDS results and correspondence analysis, creaminess and thickness were the key drivers of liking in the two dairy products. The lack of significant drivers of mouthfeel liking in dairy yogurts could be due to small sample size. Penalty-lift analysis might lose its robustness (Meyners, Castura, & Carr, 2013), when the sample size is too small. As seen in penalty-lift analyses, no mouthfeel attribute during the first 5 s was determined as key driver of liking. This could be due to the slow response time or due to other sensory attributes being drivers of liking during the first 5 s.

4.3. Reliability of the sensory method

Dynamic sensory characterizations describe how consumers perceive the mouthfeel sensation during mastication. The maximum value of dominance rate and area under the TDS curves are connected within the same product which indicates these parameters are both good for discriminating the dominances. Attribute durations show clearly the significant differences between the attributes, and thus it is an effective parameter for discriminating attributes. The results support previous results by Ares, Alcaire, Antúnez, Vidal, Giménez, and Castura (2017) and Meyners (2016) that correspondence analysis and penalty-lift analyses are complementary tools to explain the drivers of liking.

There has been discussion on the meaning of the “dominant” attribute. As Varela, Antúnez, Carlehög, Alcaire, Castura, and Berget (2018) and Ares, Alcaire, Antúnez, Vidal, Giménez, and Castura (2017) hypothesize, TDS results might tell more about the preference of the products rather than about the temporal texture characteristics which could mean that foaminess and stickiness are considered as negative drivers of liking and therefore have not been selected during the TDS evaluation. Further research is needed to find out whether the dominant attributes can be used to predict hedonic reactions to products (Varela, Antúnez, Carlehög, Alcaire, Castura, & Berget, 2018). Heterogeneity in consumer preference patterns may lead to dispersion of TDS data and low number of significantly dominant attributes (Ares, Alcaire, Antúnez, Vidal, Giménez, & Castura, 2017).This might be the case in our results as sticky and foamy were not significantly dominant in any of the products. For this reason, it can be concluded that the TDS data should also be explored in different panels. In addition, familiarity of attributes thickness, creaminess, thinness, and wateriness might explain the significances over foaminess and stickiness (Varela, Antúnez, Carlehög, Alcaire, Castura, & Berget, 2018). Previous research on semi-solid foods have reported that perceived creaminess was correlated with attributes “thick”, “smooth”, and “slippery” (Kokini, Poole, Mason, Miller, & Stier, 1984), which could indicate that the attributes creamy and sticky were partly overlapping attributes. Furthermore, as texture is a multidimensional sensory property (Szczesniak, 2002), it is interesting to find out whether some descriptors for example sticky would be more related to visual perception rather than tactile sensation.

According to the results from DSI groups and liking scores, the Innovator group shows greater liking for the plant-based products than the Laggards. This could be due to either the group being more innovative or them being more interested in plant-based products. The three groups were too small to reveal the drivers of liking reliably. Thus, more research should be conducted on the drivers of liking among larger consumer groups. Innovative consumers are more likely to try and use new products than less innovative consumers (Huotilainen, Pirttilä-Backman, & Tuorila, 2006) and are thus an interesting consumer group from the point of view of product development.

4.4. Limitations of the study

The present study was conducted with samples varying in their ingredients and composition. Further research should be conducted on the impact of compositional factors on mouthfeel perception by systematically manipulating the specific sensory characteristics such as b-glucan molecular weight distribution in oat products. Moreover, studies involving more heterogeneous subjects could contribute to deepen our understanding of consumer acceptance in plant-based yogurt alternatives. Another limitation of study is the lack of taste properties in TDS method. In this study, mouthfeel liking was used to measure the drivers of liking, and not the overall liking. This emphasizes the results from only mouthfeel perspective. However, there are many other factors contributing the liking such as taste, appearance, and overall flavor profile. Further research is necessary to determine the other drivers of liking and disliking plant-based yogurts.

5. Conclusions

The results demonstrate how typical attributes used to describe dairy yogurts are also relevant for describing non-dairy yogurts. Results suggest that mouthfeel perception in both non-dairy yogurt alternatives and dairy yogurts is a dynamic process. Plant-based yogurts showed more variation in the mouthfeel sensation after the beginning of mastication, potentially when the food is broken down by oral processing and mixture of saliva with its enzymes whereas in dairy yogurts, the mouthfeel sensation was more stable. The variation in plant-based products could be due to fracture properties, ingredients such as fat or starch content, or amylase content of saliva. Further studies should be conducted to specify which factors have the strongest impact on the breakdown of the product in mouth. The results suggest that the first impression of the mouthfeel plays a more important role in mouthfeel liking than attributes perceived later during mastication. In summary, mouthfeel plays an important role in overall liking in semisolid plant-based yogurt alternatives. Thickness and creaminess are the main drivers of liking and on the hand, wateriness and thinness are the main drivers of disliking in such products. In order to develop commercially successful plant-based yogurts, these factors should be taken into consideration during product development phase.

CRediT authorship contribution statement

Maija Greis: Writing - original draft, Investigation, Formal analysis. **Taru Sainio:** Methodology, Writing - review & editing. **Kati Katina:** Supervision, Writing - review & editing. **Amanda J. Kinchla:** Writing - review & editing. **Alissa Nolden:** Writing - review & editing. **Riitta Partanen:** Supervision, Writing - review & editing. **Laila Seppä:** Supervision, Conceptualization, Writing - review & editing.

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Appendix 1

Table A1
Questions related to a domain specific innovativeness scale (DSI).

Question
1. I will not buy plan-based yogurts, if I have not tasted them yet.
2. In general, I am the last in my circle of friends to know the trademarks of plant-based yogurts.
3. Even though plant-based yogurts are available in the store, I do not buy them.
4. I buy new plant-based yogurts before other people do.
5. In general, I am the first in my circle of friends to buy plan-based yogurts when they are available in stores.
6. Compared to my friends I buy more plant-based yogurts.

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