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Differences in dynamic sensory perception between reformulated hazelnut chocolate spreads decrease when spreads are consumed with breads and wafers

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ABSTRACT

Many foods such as breads and wafers (carrier foods) are commonly consumed in combination with spreads such as jam, peanut butter and chocolate spreads. Sensory assessments are typically performed with carrier foods or spreads alone rather than with combinations thereof. The aim of this study was to investigate the effect of carrier addition (bread, wafer) on dynamic sensory perception of chocolate hazelnut spreads varying in composition. Three chocolate hazelnut spreads varying in fat and sugar content (high fat/high sugar (reference); high fat/low sugar; low fat/high sugar) were combined with two carriers (bread and wafer). Dynamic sensory perception was determined by a consumer panel using TCATA ($n = 72$) and TDS ($n = 72$) with three chocolate hazelnut spreads without carriers and six carrier-spread combinations. Stickiness and mouth drying were considerably more dominant for low fat/high sugar spreads compared to high fat/high sugar spreads. Addition of carriers (bread and wafer) influenced dynamic sensory perception of spreads and especially reduced stickiness. In the beginning of mastication of carrier-spread combinations, perception was dominated by sensations related to carriers while at later stages of mastication, sensations related to spreads were dominant. Addition of carriers to spreads decreased consumers' ability to discriminate between spreads differing in composition. TCATA allowed to discriminate better between spreads and TDS revealed the temporality of sensations clearer. We conclude that dynamic perceptual differences between hazelnut chocolate spreads differing in composition diminish when spreads are consumed with breads and wafers. These findings provide product sensory profiles which are closer to the natural consumption context of spreads.

1. Introduction

Many foods such as breads, or wafer biscuits (carrier foods) are commonly consumed in combination with spreads such as jam, peanut butter, or chocolate spreads. Sensory assessments are typically performed with carrier foods or spreads alone rather than with combinations thereof which may limit the validity of the sensory profiles which are obtained. In contrast to many studies investigating sensory properties of carrier foods and spreads consumed alone, only very few studies explored sensory properties of combinations of foods (Cherdchu and Chambers, 2014; Nguyen and Wismer, 2020; Paulsen et al., 2012; Scarborough et al., 2012; van Eck, Fogliano, Galindo-Cuspinera, Scholten, & Stieger, 2019). This lack of data is especially surprising given that many spreads such as jam or mayonnaises are hardly ever consumed alone. Characterizing composite foods is of interest because they are more representative of the natural consumption context. Composition, mechanical properties, and sensory characteristics of the carrier foods differ considerably from those of the spreads (de Lavergne et al., 2016; Scholten, 2017). Combining carrier foods with spreads increases the sensory complexity of products, as the characteristics of one component influence the sensory perception of the other (Paulsen et al., 2012; Santagiuliana, Christaki, Piqueras-Fiszman, Scholten, & Stieger, 2018; Santagiuliana, Piqueras-Fiszman, van der Linden, Stieger, & Scholten, 2018; Scholten, 2017; van Eck, Hardeman, et al., 2019). van Eck, Fogliano et al. (2019), van Eck, Hardeman et al. (2019) demonstrated that for composite foods, carriers (bread and crackers) tend to

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dominate texture perception, whereas condiments or toppings (firm cheese, cheese spread and mayonnaise) dominated flavour perception (van Eck, Hardeman, et al., 2019). In general, it has been shown that flavor intensity of sauces and condiments is decreased by addition of carriers (Cherdchu and Chambers, 2014; Meinert et al., 2011; Nguyen and Wismer, 2020; Paulsen et al., 2012; van Eck et al., 2021). Consequently, perceptual differences between spreads or toppings can disappear upon addition of carriers since sensitivity to detect sensory differences between them may decrease (Nguyen and Wismer, 2020; van Eck, Hardeman, et al., 2019). van Eck, Fogliano et al. (2019), van Eck, Hardeman et al. (2019) showed that consumer sensitivity to discriminate between condiments varying in fat content and/or viscosity decreased with the addition of carriers. Nguyen and Wismer (2020) showed that consumer's ability to identify sensory attribute differences between regular and reformulated salt-reduced products decreased upon the addition of companion foods. This aspect is relevant for food reformulation strategies aiming at changing the nutritional composition of foods (i.e. reduction of fat and sugar content). These strategies typically require that the reformulation does not lead to changes in product sensory perception and consumer acceptance. When perceptual differences between reformulated spreads disappear once spreads are consumed with carriers, it implies that the product reformulation space may actually be larger, so that greater reductions in fat and sugar content may be achieved without consumers perceiving differences between products (Guichard, 2002).

As sensory perception is a dynamic process (Piggott, 2000), temporal sensory evaluations became more common (Heymann & Lawless, 2013). Temporal Dominance of Sensations (TDS) has been extensively used to assess dynamic sensory perception of a broad range of single foods and beverages (de Lavergne et al., 2015; de Medeiros et al., 2020; Dinnella et al., 2012; Jourdren et al., 2016; Oberrauter et al., 2018; van Bommel et al., 2019). In addition, it was shown that with a quick familiarization and by explaining the list of attributes, TDS becomes feasible for a consumer panel (Albert et al., 2012; Brachet et al., 2014; Thomas et al., 2015; Visalli et al., 2016). TDS has been applied less to evaluate heterogeneous foods or composite foods. However, for heterogeneous foods displaying contrasting texture sensations, the selection of a single attribute at a time as dominant may give rise to dumping effects (Varela et al., 2018). Temporal-Check-All-That-Apply (TCATA) may provide a more complete description of the dynamic sensory characteristics of a product, since multiple attributes from different modalities (e.g. taste and texture) can be selected simultaneously. This permits the description of sensations that arise concurrently decreasing the likelihood for dumping effects (Castura et al., 2016). Moreover, TCATA has been also used with both expert and consumer panels (Jaeger et al., 2018; Ramsey et al., 2018; Reyes et al., 2017). Multiple studies compared TDS and TCATA and suggested that TCATA may provide a better sensory discrimination between samples than TDS (Ares et al., 2015;. Nguyen et al., 2018). The selection of an adequate dynamic sensory method depends largely on the research question and on the product properties such as food heterogeneity (i.e., composite foods) and food sensory complexity. Few studies have determined sensory properties of composite foods and the methodologies used include Quantitative Descriptive Analysis (QDA), Descriptive Analysis (DA), Temporal Dominance of Sensations (TDS), Rate-All-That-Apply (RATA), Flash Profiling (FP), Sequential Profiling (SP) and Progressive Profiling (PP) (van Eck & Stieger, 2020). To our knowledge TCATA has not been used to evaluate dynamic sensory properties of composite foods. Thus, it remains unclear which temporal sensory method (TDS or TCATA) is more adequate to capture the dynamics of sensory perception of sensorial more complex composite foods.

The aim of this study was to investigate the effect of carrier addition (bread, wafer) on dynamic sensory perception of chocolate hazelnut spreads varying in composition using TDS and TCATA. TDS was used in addition to TCATA (a) to allow for comparison of dynamic sensory properties of composite foods with previous studies which used TDS, (b) to validate the findings of previous studies comparing the TCATA and TDS methodologies and (c) to extend the findings of previous studies comparing the TCATA and TDS methodologies from single to sensorial more complex composite foods. We hypothesize that (i) addition of carriers to spreads causes dominance of texture sensations related to carriers and decreases dominance of sensations related to spreads, (ii) discrimination sensitivity between reformulated spreads decreases when spreads are combined with carriers and (iii) TCATA provides better sensory characterization of composite foods than TDS since participants select multiple sensory attributes at the same time.

2. Materials and methods

2.1. Samples

The composition of all chocolate hazelnut spreads together with their rheological properties are summarized in Table 1**.** Three chocolate hazelnut spreads varying in fat and sugar content (high fat/high sugar referred to as C (Control sample); high fat/ low sugar (15% sugar reduction referred to as LS); low fat/ high sugar (15% fat reduction referred to as LF) were prepared using milk and inulin to replace fat and sugar respectively. Composite foods were prepared by combining spreads with two carriers with different mechanical and texture properties (bread and wafer). Spreads have been reformulated to warrant close resemblance to real commercial products. Preparing a low fat/low sugar chocolate hazelnut spread would have changed the organoleptic characteristics of the chocolate spread to a degree that it would have no longer been comparable with the other spreads. For this reason, it was not possible to have a complete factorial design of the study. Bread and wafer were chosen as carriers to simulate the consumption context of the chocolate hazelnut spreads with high ecological validity. The most common consumption context for chocolate hazelnut spreads is consumption with breads. The wafer filled with chocolate hazelnut spread represents a globally, commercially available composite food that differs in mechanical and texture properties from bread. A description of sample codes is shown in Table 2.

All samples included 6 g of spread. The spreads evaluated alone (6 g) were served on a plastic spoon. For the spread-wafer combinations, wafer biscuits (Soremartec, Italy) were pre-cut in the form of a shell with dimensions of 3 × 4 × 1 cm (mean weight 1.56 ± 0.1 g), filled with the spread (6 g) and packed. They were kept in their original package at room temperature (21 ± 1 °C), protected from sunlight, and were opened just before the evaluation. For the spread-bread combinations, commercially available bread (Morato Bruschelle, Italy) was cut into cubes of 3 × 3 × 1 cm without crust (mean weight 2.23 ± 0.5 g), and

Table 1
Overview of composition of chocolate hazelnut spreads and their rheological properties.

	Chocolate hazelnut spreads		
	High fat/High sugar (Control C)	High fat/ Low sugar (LS)	Low fat / High sugar (LF)
Sugar [g/100 g]	51.69	43.94	53.69
Roasted hazelnuts [g/ 100 g]	10.20	10.20	10.20
Cocoa [g/100 g]	5.48	5.48	5.48
Skimmed milk powder [g/100 g]	10.95	10.95	12.13
Lecithin [g/100 g]	0.43	0.43	0.43
Vanillin [g/100 g]	0.02	0.02	0.02
Oil [g/100 g]	21.03	21.03	17.85
Inulin [g/100 g]	–	7.75	–
Aroma Mix [g/100 g]	0.20	0.20	0.20
Consistency (K) [Pa*s^n]	105.5	153.9	165.5
Flow behaviour index (n)	0.45	0.37	0.34

Table 2
Overview of sample labels of all stimuli.

Spread Group	High fat/ High sugar (Control C)	High fat/ Low sugar (LS)	Low fat / High sugar (LF)
 **Alone (A)** (6 g)	A-C	A-LF	A-LS
 **Bread- Spread (B)** 3x3x1cm (mean weight bread 2.23 ± 0.5 g)	B-C	B-LF	B-LS
 **Wafer – Spread (W)** 3x4x1 cm (mean weight wafer 1.56 ± 0.1 g),	W-C	W-LF	W-LS

spread (6 g) was spread on top of the bread with a knife. The spread-bread and the spreads evaluated alone were prepared just before the evaluation (<2 h).

2.2. Rheological characterization of spreads

Flow curves of three chocolate hazelnut spreads were determined using a Physica MCR 301 Rheometer (Anton Paar GmbH, Graz, Austria) at 20 °C with a smooth parallel plate geometry and stainless-steel probe (PP50/SS 61717). 2 ml of each spread was put onto the plate, which was fixed on a Peltier system with the temperature fixed at 20.0 ± 0.1 °C. The excess sample squeezed out of the gap was removed with a spatula in the trimming position and from the edge of the upper geometry. An inspection was done after trimming to avoid air remaining in the measuring gap. The samples were equilibrated for 5 min before the analysis began. Flow curves of spreads were measured by recording shear stress values when shearing the samples with an increasing shear rate from 0.1 to 1000 s-1 and then decreasing shear rate from 1000 to 0.1 s-1 in 3.5 min. During each interval 21 data points were measured, with each point being held for 5 s. Measurements were carried out in triplicate. The Ostwald-de-Waele power law model (**equation (1)**) was used to fit the flow curves to quantify consistency (*K)* and flow behaviour index (***n)***. Fitting of flow curves was done at shear rates ranging from 1 to 100 s-1.

$$\eta = K^{*}\gamma^{n} \quad (1)$$

2.3. Participants

As the focus of the study was to understand perception of composite foods varying in properties, a relatively homogeneous group of participants was selected to control as much as possible inter-individual variation. Thus, one hundred forty-four healthy women (18–29 yrs) were recruited for this study from the consumer database of the Centrum voor Smaakonderzoek (CSO, "Center for Taste Research", Wageningen, The Netherlands). All participants were Caucasian women that consumed chocolate hazelnut spreads at least once a month (self-reported). Other inclusion criteria were to not have any dietary restrictions, nor allergy or intolerances to wheat/gluten, dairy, nuts, soybean, or eggs, to not be pregnant, non-smoking and with no history of oral perception disorders or olfactory impairments (self-reported). None of the participants had any previous training in sensory evaluation of chocolate hazelnut spreads. After inclusion, participants were randomly divided in two groups to perform sensory evaluations either with TCATA (n = 72, mean age 22.6 ± 2.0 yrs, mean BMI 21.9 ± 2.6 kg/m2) or TDS (n = 72, mean age 23.0 ± 2.0 yrs, mean BMI 22.1 ± 2.6 kg/m2). No significant differences were observed for age, BMI, desire to eat or hunger levels at the beginning of sensory evaluations between the TCATA and TDS groups according to Mann-Whitney test ($p > 0.05$). Participants gave written informed consent before the start of the study and received financial compensation for their participation.

2.4. Attribute selection and determination of consumption time

Sensory attributes were selected by eight women (mean age 34.2 ± 7.4 yrs., mean BMI 25.3 ± 4.3 kg/m^2) not participating in the sensory evaluation of the study. This focus group underwent through four familiarization sessions of one hour each for the evaluation of chocolate hazelnut spreads. The first two sessions were dedicated to attribute generation focused on descriptors related to flavour and texture of the spreads and the spread-carrier combinations. The attributes that were most frequently mentioned were included in the final attribute lists used in the evaluations. Different attribute lists were used for the evaluations of spreads alone and for the carrier-spread combinations. Eight sensory attributes were included for the spreads when evaluated alone, and 10 for the spread-wafer and spread-bread combinations. The list of attributes and their definitions are shown in Table 3. The eight women that generated the attribute list, also determined the consumption time for all samples. They took the sample in their mouth, masticated the samples naturally and swallowed them. They were asked to indicate when they swallowed the sample by raising their hand. The total consumption time was obtained by the researcher with a timer and was defined as the time period between taking the sample into the mouth and swallowing for each participant (i.e. raising the hand). The average total consumption time (n = 8) for spreads consumed alone was 15 s and for carrier-spreads

Table 3
List of sensory attributes and definitions used for TDS and TCATA evaluations. Different attribute lists were used for evaluations of spreads alone and for carrier-spread combinations.

Attribute	Definition	Spread Alone	Bread+Spread	Wafer + Spread
Hazelnut	Flavour associated to roasted hazelnut	✔	✔	✔
Milky	Flavour associated with processed milk such as milk powder	✔	✔	✔
Sweet	Taste associated with sugar	✔	✔	✔
Toffee	Flavour associated to caramel toffee	✔	✔	✔
Cocoa	Flavour associated with cocoa powder	✔	✔	✔
Creamy	Sensation related to a full, soft and smooth texture	✔	✔	✔
Mouth drying	Sensation related to a dry and rough feeling on the tongue and oral cavity	✔	✔	✔
Sticky	Adhesion of the product to the palate, tongue and teeth	✔	✔	✔
Bread-like	Flavour associated with bread, grain flour.		✔	
Pasty	Sensation related to consistent, thick dough.		✔	
Wafer-like	Flavour associated with wafers and dry biscuits			✔
Crunchy	Auditory and tactile sensation linked to a crunching sound when chewed			✔

combinations 20 s. During the TCATA and TDS evaluations (section 2.6 and 2.7), participants were instructed to swallow the samples at these times.

2.5. Procedure

Sensory evaluations took place in a testing room under normal light conditions at room temperature (21 ± 1 °C). Participants evaluated nine samples (Table 2) in one session of 60 min with two minutes break in between each sample. They received the attribute lists and definitions (Table 3) by email the day before their scheduled session and were instructed to familiarize themselves with them. Participants were asked not to smoke, eat, drink, or use any persistent-flavoured product for at least one hour before their session. On the day of the evaluation, a short demonstration of either the TCATA or TDS procedure was given, after which participants were asked if there were any remaining questions about the attribute lists that they received. Participants were then seated individually and were provided with the list of attributes and their definitions and a tablet on which the test was performed. The sensory assessment started with a warm-up sample (cracker) so that participants familiarized themselves with the sensory method and software that was used throughout the whole evaluation to gather data (TimeSens software version 1.1.601.0, ChemoSens, FR).

All samples were served at room temperature (21 ± 1 °C) in standardized bite size. Spreads alone (6 g) were served on a plastic spoon. Spread-bread and spread-wafer combinations were placed on paper plates. Samples were coded with a random three-digit number and presented on three different trays which were presented to participants in blocks (spreads alone, bread-spread combinations, wafer-spread combinations) so that each tray had three formulations of spread (C, LS, LF). The order of trays was counterbalanced across participants and the order of spread formulations within each tray was randomized. The attributes were presented simultaneously on the tablet and their order was randomized across participants. In between samples, participants were asked to rinse their mouth with water. Participants rated their hunger level on a 100 mm Visual Analogue Scale (VAS) with end anchors 'not at all' to 'extremely' before and after all samples were assessed

2.6. Temporal-Check-All-That-Apply (TCATA)

Participants ($n = 72$) were instructed to click on a start button concurrently with taking the whole sample in their mouth. At any time between clicking start and the end of the evaluation time, participants were asked to check the terms that apply to describe the sensory characteristics of the sample at each moment and to uncheck the terms when they no longer apply to describe the sample. Participants could select as many attributes as they liked, use the same attribute several times or never select an attribute. Precise instructions were given regarding the moment at which assessors were asked to swallow the sample by flashing the word 'swallow' on the tablet screen. Spreads alone were swallowed 15 s and carrier-spreads combinations 20 s after clicking the start button which corresponds to the natural consumption time of these foods (section 2.4). TCATA data collection was stopped automatically 105 s after participants clicked the start button.

2.7. Temporal dominance of sensations (TDS)

Participants ($n = 72$) were instructed to click on a start button concurrently with taking the whole sample in their mouth. When participants did not perceive any sensations anymore, they were instructed to click on the "Do not perceive anything anymore" button to stop TDS data collection. Immediately after taking a sample into their mouth, participants were asked to start selecting the most dominant sensation at each moment in time. Dominant was defined as the attribute that caught most of their attention. An attribute remained dominant until another attribute was selected. Attributes could be dominant selected several times during the evaluation and not all attributes had to be selected as dominant. Similar to the TCATA evaluations, participants were instructed to swallow spreads alone after 15 s and carrier-spreads combinations after 20 s after pushing the start button by flashing the word 'swallow' on the tablet screen. These time periods correspond to the natural consumption time of these foods (section 2.4)

2.8. Data analysis

2.8.1. TCATA curves

TCATA curves were constructed following the procedures described by Castura et al. (2016). Proportions of citations for each attribute were calculated as the proportion of participants who checked (or perceived) a given attribute at a given moment (every 0.1 s) during the evaluation period. For a better visualization, smoothing of TCATA curves was performed using the smooth function of the TempR package of R software version 3.1.1.

For each group of products (spread alone, bread-spread and wafer-spread combinations), the citation proportions of the control samples (A-C, B-C and W-C) were compared to the citation proportions of the corresponding test samples (A-LF and A-LS; B-LS and B-LS; W-LF and W-LS). Significant differences in TCATA profiles of two products were obtained by applying two-sided Fisher–Irwin tests for each time point and for each attribute to evaluate whether citation proportions for the pairs of products were statistically significant from zero at the 5% significance level (Castura et al., 2016). In this study, we examined how the reformulated chocolate hazelnut spreads (High fat/ Low sugar (LS); Low fat/High sugar (LF)) differed from the reference chocolate hazelnut spread (High fat/High sugar (Control C)) regarding their dynamic sensory perception when consumed with and without carriers. Therefore, pairwise product difference between the reference product and the reformulated were performed. Highlighted sections in the TCATA curves (bold lines) represent periods during which significant differences between test sample and control sample were observed ($p < 0.05$).

2.8.2. TDS curves

TDS curves were constructed following the procedures described by Pineau et al. (2009). The dominance rate for each attribute at a given moment (every 0.1 s) was determined as the proportion of participants for which the given attribute was selected as dominant sensation. Chance and significance lines were calculated at $p = 0.05$ and added to the TDS curves as described by Pineau et al. (2009). For a better visualization, smoothing of TDS curves was performed using the smooth function of the TempR package of R software version 3.1.1.

For each group of products (spread alone, bread-spread and wafer-spread combinations), the dominance rates of TDS of the control samples (A-C, B-C and W-C) were compared to the dominance rates of the corresponding test samples (A-LF and A-LS; B-LS and B-LS; W-LF and W-LS). Just as with TCATA curves, limits of significance of the difference in dominance rates were obtained with Fisher's exact test (Castura et al., 2016) as the same statistical analysis as TCATA was used for pairwise comparison of the samples, independently from the significance levels of the TDS curves. Highlighted sections in the TDS curves (bold lines) represent periods during which significant differences between test sample and control sample were observed ($p < 0.05$).

2.8.3. Duration analysis

For each temporal method, three linear mixed models were performed by group of products separately (A, B, W) with average citation durations in the case of TCATA and dominance durations in the case of TDS data, for a specific attribute as response. The type of formulation (C, LS, LF) was set as fixed factor and participants as random effect. Three PCAs with confidence ellipses of 0.90 were obtained for each product (A, B, W) for both, TCATA and TDS data to analyse the relationships between sensory attributes within the different formulations. Only the descriptors with a significant p value ($p < 0.05$) were included in the map. Data analysis was done with XLSTAT (XLStat ver. 2021, Sensory Package, Addinsoft, Paris, France). Only the PCAs obtained with the citation durations from TCATA data were included in section 3, while the ones obtained with TDS dominance durations were included in the Supplementary material.

2.8.4. Product trajectories

Mean citation proportions and dominance rates of the TCATA and TDS data respectively, were structured such that *Product* × *Time* was arranged in rows and Attributes in columns (Castura et al., 2016). PCA sensory trajectories describing the evolution of sensory perception over time were obtained at different time intervals. Trajectories were built and smoothed using the tempR package of R software version 3.1.1. Only the trajectories from the TDS data were included in section 3, whereas the trajectories obtained with TCATA data were included in the Supplementary material.

3. Results

3.1. Dynamic sensory perception of spreads alone

Fig. 1 shows the TCATA (1A,1B,1C) and TDS (1D,1E,1F) curves for the three chocolate-hazelnut spreads when consumed alone (A-C, A-LF and A-LS).

The highest citation proportions (TCATA) for the control spread were sweetness (0.87), followed by hazelnut (0.79) and stickiness (0.79) sensations. The reduced fat spread (A-LF) was perceived significantly ($p < 0.05$) stickier, with an average increase of 0.24 of citation proportions, compared to the control spread (A-C) throughout the entire evaluation period. Citation proportions of the reduced fat spread (A-LF) of milky, decreased 0.21 ($p < 0.05$) at the beginning of mastication and after the swallowing moment, compared to the control (A-C), whereas mouth drying applicability significantly increased 0.22, specially before and after swallowing for A-LF compared with A-C. Sweetness, creamy and hazelnut sensations of A-LF showed a significant decrease ($p < 0.05$) of citation proportions of 0.17, 0.17 and 0.19 respectively, compared to A-

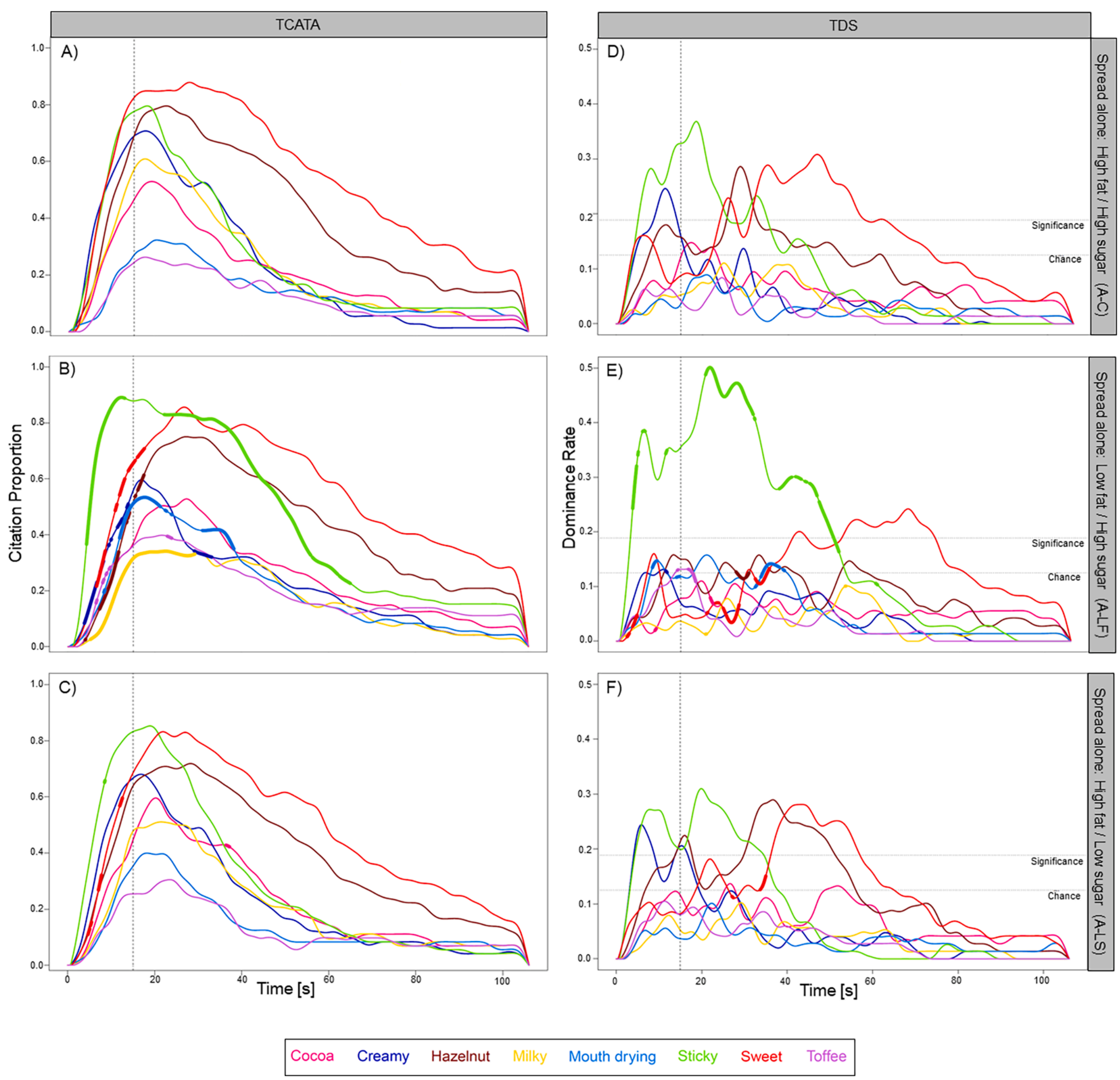

Fig. 1. TCATA (n = 72) and TDS (n = 72) curves for the three chocolate hazelnut spreads served on their own (A-C, A-LF, A-LS). Periods of significant differences ($p < 0.05$) in proportion of citations (TCATA) and dominance rates (TDS), between the A-LF and A-LS compared to A-C, are indicated by highlighted thick sections. The vertical dotted line represents the swallowing moment.

C in the beginning of mastication. The TCATA sensory profile of the reduced sugar spread (A-LS) was very similar to that of the control spread (A-C), except for short periods (<3 s) in the beginning of the evaluation during which sweetness applicability was significantly lower (0.14) for A-LS compared to A-C.

As for the TDS evaluations, the control spread (A-C) was characterized by dominance of sticky and creamy sensations during mastication. Sticky remained dominant sensation after swallowing and then, hazelnut followed by sweetness were dominant sensations after swallowing. For the reduced fat spread (A-LF), dominance of sticky sensation significantly increased 0.19 compared to the control spread (A-C), throughout most of the evaluation time and creamy sensations of the reduced fat spread (A-LF) did not reach significance during and after mastication. Sweetness was perceived as dominant in the middle and towards the end of the evaluation. The TDS sensory profile of the reduced sugar spread (A-LS) was characterized by creamy sensation in the beginning, sticky sensation before and after the swallowing moment, followed by dominance of hazelnut and sweetness after swallowing. No significant differences were observed between the TDS profiles of the reduced sugar spread (A-LS) and the control formulation (A-C).

To summarize, TCATA and TDS evaluations of the spreads alone showed similarly that dynamic sensory perception of the high fat/low sugar spread (A-LS) was very similar to the control spread (A-C) and that the low fat/high sugar spread (A-LS) was perceived stickier than the control spread (A-C) and less sweet during the mastication.

3.2. Dynamic sensory perception of spreads with carriers

Figs. 2 and 3 show the TCATA and TDS curves for the three chocolate hazelnut spreads combined with bread (B-C, B-LF and B-LS, Fig. 2) and wafer (W-C, W-LF and W-LS, Fig. 3), respectively.

As expected, the addition of carriers (bread and wafer) to spreads influenced dynamic sensory perception of all spreads considerably. For TCATA and TDS, during the beginning of consumption, sensations related to the flavour and texture of the carriers, such as bread-like flavour for the bread-spread combinations, and wafer-like flavour and crunchy for the wafer-spread combinations were characteristic. For the bread-spread combinations (B-C, B-LF and B-LS) in the TCATA evaluation, after the swallowing moment sweetness and hazelnut showed the highest citation proportions with 0.83 and 0.72 respectively and lingered until the end of evaluation time. While the B-LS combination displayed a very similar temporal profile as the B-C combination, the B-LF combination showed a significant increase of 0.21 citation proportions of sticky, especially after swallowing.

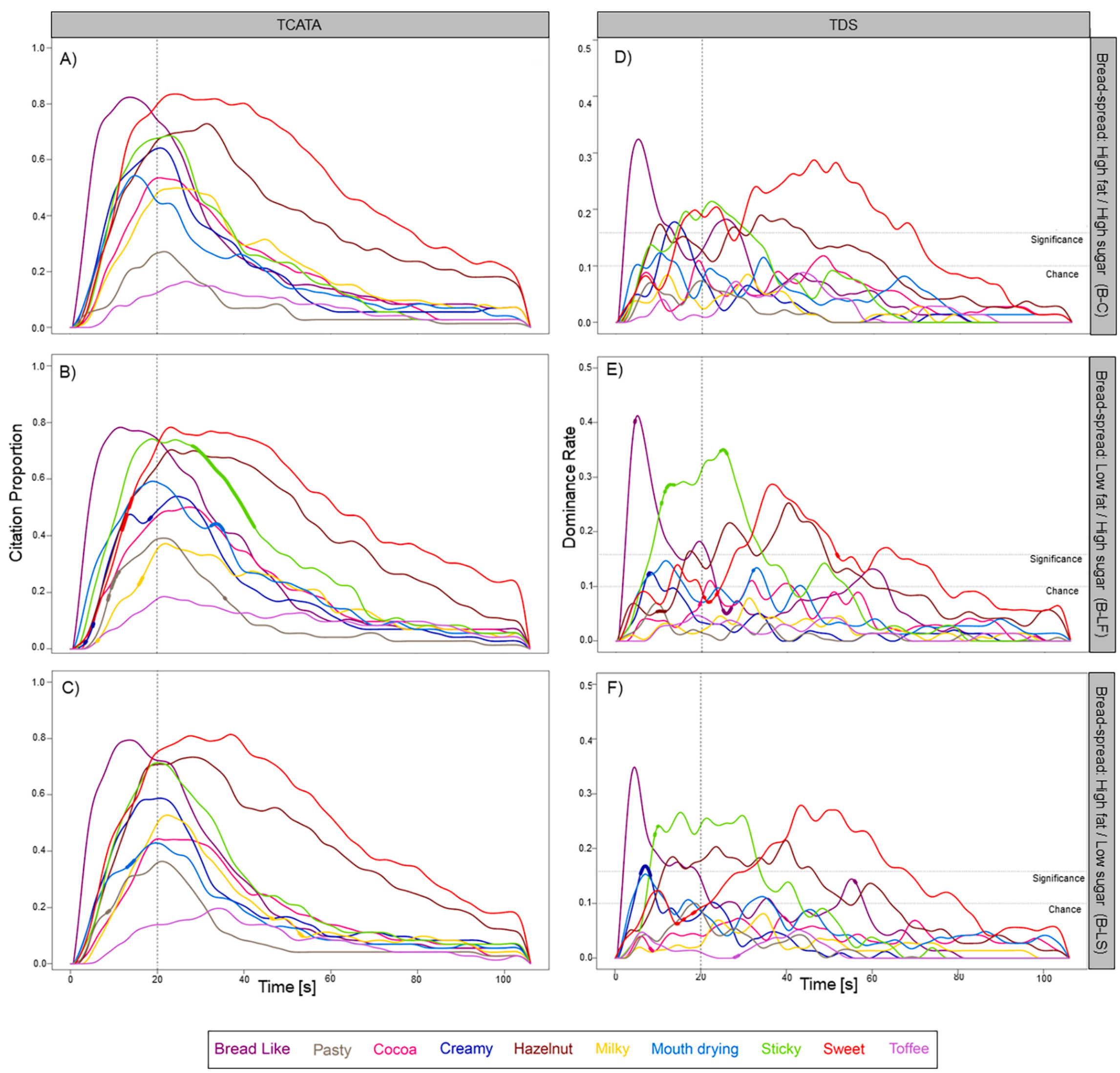

Fig. 2. TCATA (n = 72) and TDS (n = 72) curves for the three chocolate hazelnut spreads combined with bread (B-C, B-LF and B-LS). Periods of significant differences ($p < 0.05$) in proportion of citations (TCATA) and dominance rates (TDS), between the B-LF and B-LS compared to B-C, are indicated by highlighted thick sections. The vertical dotted line represents the swallowing moment.

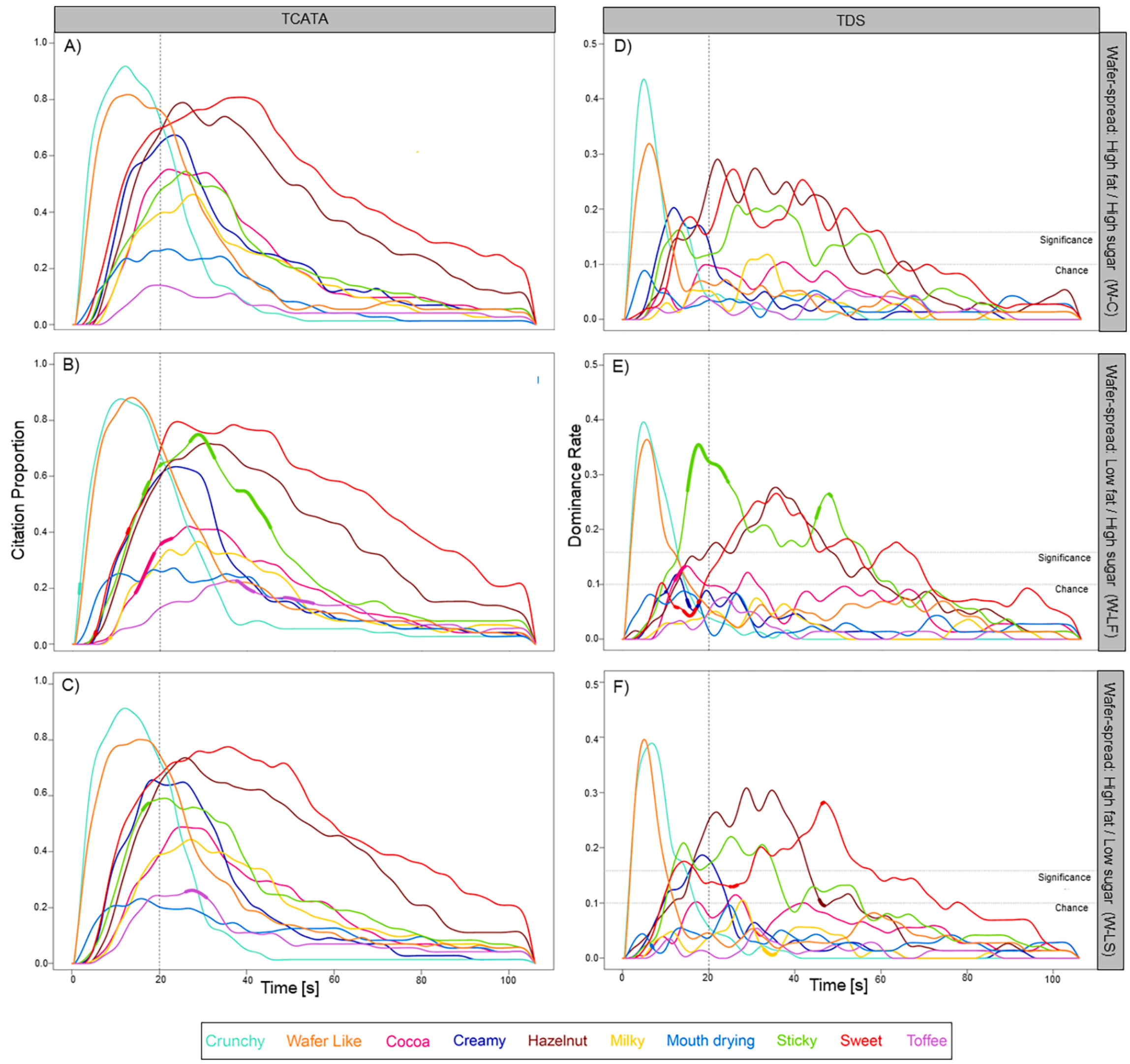

Fig. 3. TCATA (n = 72) and TDS (n = 72) curves for the three chocolate hazelnut spreads combined with wafer (W-C, W-LF and W-LS). Periods of significant differences ($p < 0.05$) in proportion of citations (TCATA) and dominance rates (TDS), between the W-LF and W-LS compared to W-C, are indicated by highlighted thick sections. The vertical dotted line represents the swallowing moment.

For the TDS evaluation, B-C and B-LS combinations displayed similar sensory profiles. The first part of mastication was dominated by the attribute bread-like flavour. For the B-LF combinations, during the beginning of mastication time bread-like flavour was dominant sensation. Before and after the swallowing moment, dominance rate of sticky sensation increased 0.154, followed by dominance of sweetness which decreased compared to B-C.

As stated before, the addition of wafer influenced the sensory perception of spreads. For TCATA and TDS evaluations, wafer-like flavour and crunchy were the characteristic attributes at the beginning of consumption time of wafer-spread combinations (W-C, W-LS, W-LF). For all combinations, creamy reached highest citation proportion in TCATA around the swallowing moment (20 s). Then, sweetness and hazelnut showed a prolonged perception after swallowing and towards the end of the evaluation time. W-LF combination displayed a significant increase in citation proportions of 0.22 in sticky sensation after the swallowing moment, an increment of 0.11 of applicability in toffee flavour around the middle part of the mastication period, and a decrease in cocoa flavour before the swallowing moment compared to the W-C. W-LS combinations showed very similar dynamic sensory profiles as W-C with only minor significant differences being found for short time periods (<3 s).

Crunchy and wafer-like sensations were dominant at the beginning of the TDS evaluation for W-C, followed by a short dominance period of creamy. After swallowing, hazelnut, sweetness and to a lesser extent, sticky, were dominant sensations through the rest of the evaluation period before decreasing gradually. W-LF on the other hand, was characterized by a significant increase of 0.20 in dominance of sticky before and after the swallowing moment followed by dominance of hazelnut and sweetness and an increase of dominance of sticky sensation in the middle of evaluation time. The beginning of the TDS profiles of W-LS were characterized by crunchy and wafer-like, followed by dominance of sticky just before the swallowing moment. There was an increase of hazelnut perception followed by sweetness. No significant differences were found between the TDS profiles of W-LS and W-C.

3.3. Duration analysis

Principal Component Analysis (PCA) of the durations of sensations from the TCATA data are shown in Fig. 4 to illustrate differences between samples. The corresponding PCAs of the dominance durations from the TDS data are shown in Supplementary Material Fig. 1. Fig. 4**A** shows the spreads when consumed alone. The first axis accounts for 82% of variability and is primarily corelated with the sensations mouth

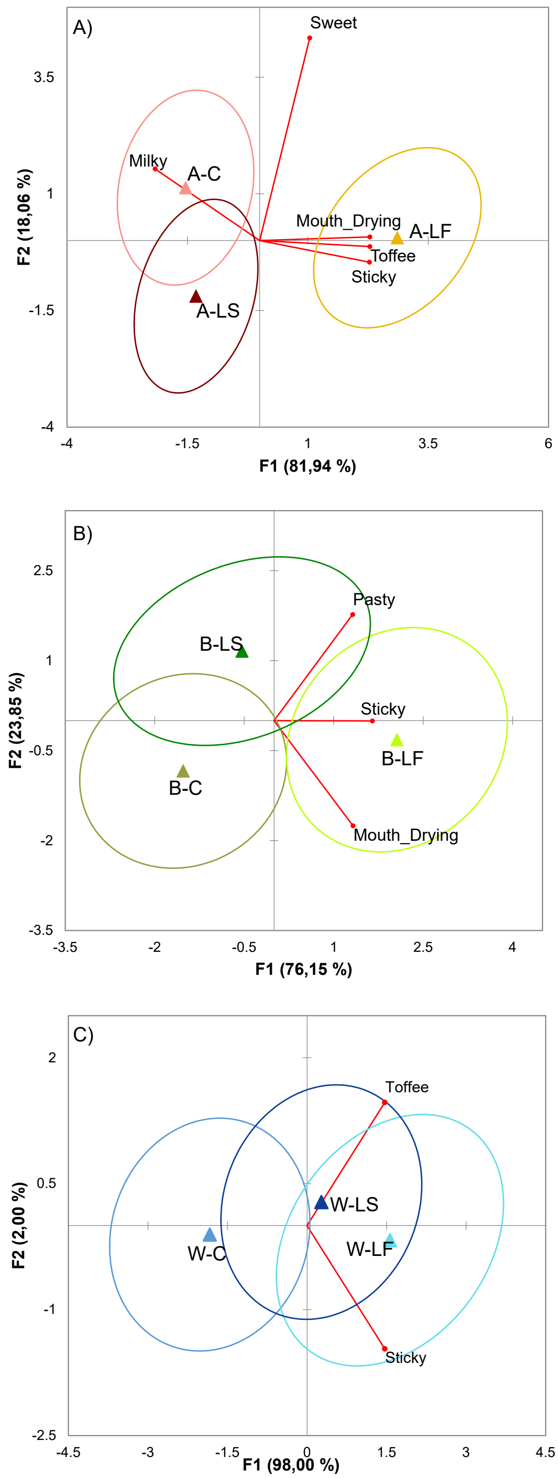

Fig. 4. Principal Component Analysis (PCA) of the durations of sensations from the TCATA data with confidence ellipses of 0.90. Biplot showing dimensions 1 and 2 represents the sensory profiles of the three chocolate hazelnut spreads (C, LF, LS) served alone (Fig. 4A), combined with bread (Fig. 4B), and combined with wafer (Fig. 4C). Only the attributes that were significantly different ($p < 0.05$) are shown.

drying, toffee and stickiness. Control spread (A-C) was particularly characterized by Milky flavour and was perceived in a similar way as the A-LS spread, with their confidence ellipses overlapping. The confidence ellipse of A-LF (depicted in yellow) does not overlap with the confidence ellipses of A-C and A-LS demonstrating that the low fat spread was perceived significantly different from the other spreads when consumed alone.

This discrimination between spreads was influenced by the addition of bread (Fig. 4**B**) and wafer (Fig. 4**C**) to the spreads. In both cases it can be observed that the sensitivity to discriminate between spreads differing in formulation, decreased. Sensory profiles of carrier-spread combinations started to overlap, especially when wafer was added. For wafer-spread combinations, the confidence ellipses of W-C, W-LS and W-LF overlap suggesting that these combinations were not discriminated although spreads differed in formulation.

From the PCA it can be observed that indeed TCATA provided a more detailed description of the samples as multiple attributes can be selected at a time. In contrast, the corresponding PCAs of dominance durations from the TDS data (Supplementary Material Fig. 1) showed a less detailed description of the samples, as fewer attributes were statistically significant ($p < 0.05$).

3.4. Sensory trajectories of spreads and carrier-spread combinations

Fig. 5 displays the temporal evolution of TDS attributes (sensory trajectories) for spreads evaluated alone, and in combination with bread and wafer. The corresponding trajectories of the TCATA attributes are provided in the Supplementary material (Fig. 2). Fig. 5**A**, displays the sensory trajectories of the spreads evaluated alone. The two components account for 85.57% of the total variance. At the beginning of consumption, spreads were differentiated according to the first dimension of the PCA, which was mainly related to sticky, whereas dimension 2 was negatively correlated with sweet and hazelnut. The trajectories for all spreads started in the top left. As evaluated by dominance rate, the early dominant attributes were mouth drying, creamy and sticky. As the evaluation continued, attributes hazelnut, toffee, cocoa, milky and sweet were dominant. When comparing the three spread formulations, A-C and A-LS displayed similar sensory trajectories. The sensory trajectory of A-LF was characterized by a high dominance rate of sticky and followed by creamy, milky, cocoa and toffee sensations.

The addition of carriers to spreads influenced the sensory trajectories. Fig. 5**B and C** display the sensory trajectories for the bread-spread and wafer-spread combinations, respectively. The first two dimensions of the PCA of the sensory trajectories for the bread-spread combinations accounted for 77.49 % of the variance observed among samples (Fig. 4B). In the beginning of the mastication, bread-like flavour and sticky were dominant sensations for all bread-spread combinations, with the B-LF combinations displaying a higher dominance rate of sticky. As the evaluation time continued, dominance of sensations evolved into hazelnut, cocoa and toffee for all bread-spread combinations. The sensory trajectories of the bread-spread combinations were independent of the spread formulation. Lastly, Fig. 5**C**, shows the sensory trajectories for the wafer-spread combinations. The two components accounted for 82.34% of the total variance. The evolution pattern from all samples was very similar across the three wafer-spread combinations. In the beginning, mastication was characterized by a high dominance rate of crunchy and wafer-like and followed by creamy, sweet, and cocoa sensations.

As mentioned previously, results indicate that TCATA provided a better discrimination between samples and less information about the temporal evolution of attributes and there dynamic sequence. This was confirmed by the corresponding trajectories of the TCATA data which are provided in the Supplementary material (Fig. 2), where in general all samples followed the same trajectory.

4. Discussion

The aim of this study was to investigate the effect of carrier addition (bread, wafer) on dynamic sensory perception of chocolate hazelnut spreads varying in composition using TDS and TCATA. It was first hypothesized that the addition of carriers to spreads causes dominance of

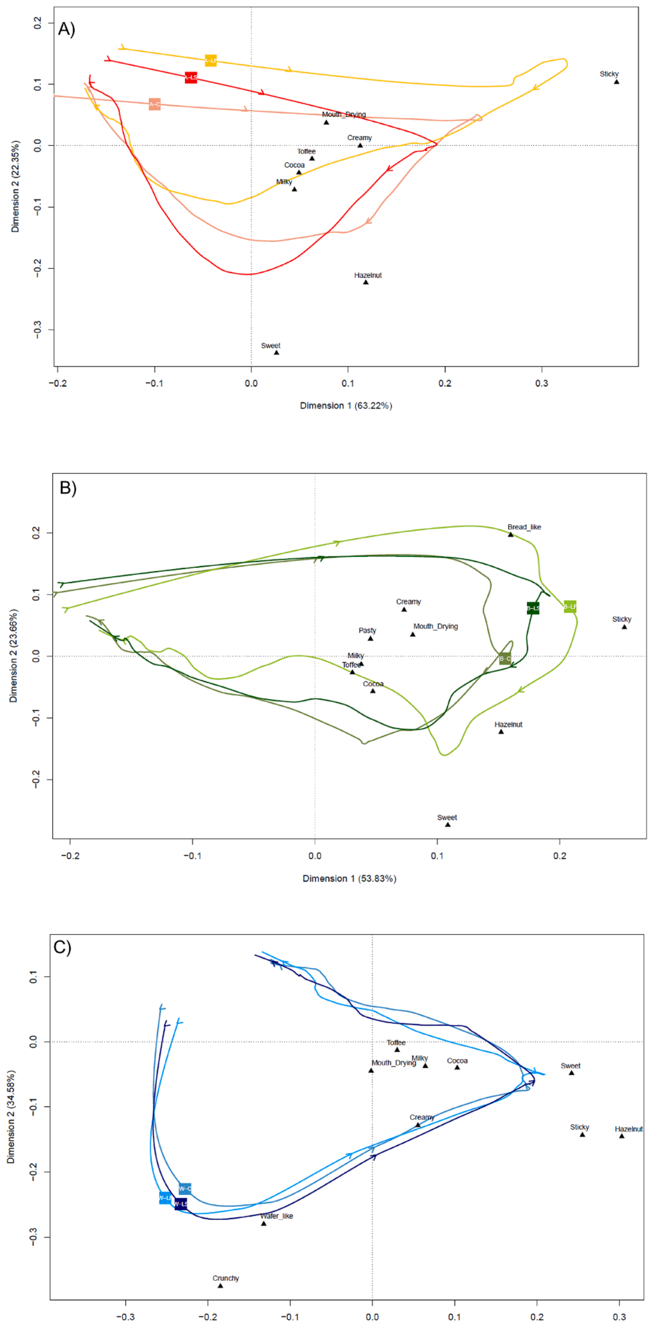

Fig. 5. Principal Component Analysis on the mean dominance rates from TDS data. Biplot showing dimensions 1 and 2 representing the sensory trajectories of the three chocolate hazelnut spreads (C, LF, LS) served alone (Fig. 5A), combined with bread (Fig. 5B), and combined with wafer (Fig. 5C). Product trajectories are smoothed, and the symbol > Indicates the direction of the trajectory at different time intervals.

texture sensations related to carriers and decreases sensations related to spreads. When carriers (bread and wafer) were added to chocolate hazelnut spreads, a component with a contrasting texture was added. The dynamic sensory profiles of the carrier-spreads combination in TCATA and TDS showed that the early stages of the consumption were dominated by attributes related to the carrier. In the case of bread combinations, bread-like flavour dominated the beginning of mastication. In the case of wafer combinations, not only flavour (wafer-like), but also texture sensations related to the mechanical properties (crunchy) dominated. In both cases, only during later stages of mastication attributes related to the spreads characterized the sensory profiles, thus our first hypothesis is confirmed. One explanation for this could be that participants' attention shifted from perception of one food component to the other within one single bite during the mastication process. It could also be that some texture sensations such as crunchiness are sensed with the first bite, whereas for taste and flavour to be perceived as dominant, tastant and volatile compounds need to be released from the food matrix to reach the gustatory and olfactory receptors which is a process that is facilitated by oral breakdown of the foods and hence, it occurs at later stages of the mastication cycle. Overall, these findings agree with a recent study where carriers (bread, carrot) and mayonnaise were combined in one bite and TDS showed that the dynamic sensory profiles of the carrier-mayonnaise combinations were dominated by the texture of the solid carriers, especially in the beginning and end of consumption, whereas additional sensations related to the mayonnaises appeared in the middle stage of consumption. (van Eck, Fogliano, et al., 2019).

It should be noted that the lists of attributes used for the spreads alone and for the carrier-spread combinations were different. For instance, the attributes related to the carriers (e.g., bread-like flavour, and pasty for the bread combination and wafer-like, and crunchy for the wafer combination) were not present in the attribute list when spreads were consumed on their own, meaning that even if they were hypothetically perceived, they were not offered in the attribute list. The number of attributes was kept to a maximum of 10, consistent with TDS methodological recommendations (Pineau et al., 2012). It was assumed that the likelihood that a carrier related attribute such as crunchy was selected when the spread was served on its own is negligible.

Secondly, it was hypothesized that the discrimination sensitivity across reformulated spreads decreases with the addition of carriers. Previous studies have shown that the influence of mono- and disaccharides on flavor release, and consequently on flavor perception, is rather limited, especially when concentration changes remain within realistic product reformulations (Delarue & Giampaoli, 2006). This could explain why the degree of sugar reduction in our study was not sufficient to induce significant differences in dynamic sensory perception between A-LS and A-C. On the contrary, reduction of fat content led to significant differences in dynamic sensory properties between A-LF and A-C. For instance, when consumed alone, the reduced fat (A-LF) spread was perceived significantly stickier than the control (A-C) and reduced sugar (A-LS) spread throughout eating time. We speculate that the change in viscosity of the spread (Table 1) caused by fat reduction might have contributed to a higher perception of stickiness. This perceptual difference between spreads disappeared when carriers were added to spreads, as the mouthfeel attribute sticky of the spreads decreased. Composite foods have an increased stimulus complexity, which may have caused a decrease in sensitivity to detect differences between reformulated spreads. This is in agreement with previous research where consumers' ability to identify sensory differences between regular and sodium-reduced foods decreased with the presence of the accompanying foods (Nguyen and Wismer, 2020). Ultimately, this indicates that current practices of evaluation of single foods that are rarely consumed on their own could give an inaccurate sensory profile and mislead product development. Based on the dynamic sensory evaluation of reformulated chocolate hazelnut spreads alone, we would conclude that the reduced fat spread (15% fat reduction) does not qualify as a reformulated spread as it does not provide a similar sensory experience as the control spread. In contrast, based on the dynamic sensory evaluation of the reformulated spreads consumed with carriers, especially wafers, we would conclude that the reduced fat spread (15% fat reduction) qualifies as a reformulated spread as it provides a similar sensory experience as the control spread when consumed with carriers, which represents a more natural consumption context. It seems that the presence of accompanying foods might distract consumer attention away from the (reformulated) product of interest, which, in fact, could give more flexibility in the design of healthier foods (e.g. low in calories, reduced fat, reduced sugar, reduced salt) as it increases the reformulation space.

In addition, an effect of the type of carrier was observed as the perception of certain attributes of spreads were affected in different ways by bread compared to wafer. For instance, decrease of stickiness was more pronounced for the wafer-spread combinations than for the bread-spread combinations. On the other hand, the presence of bread but not wafer, increased the perception of mouth drying, while the perception of milky, hazelnut and sweetness perception were reduced by addition of carrier. Even though the swallowing moment was fixed for all groups of foods, it may be that oral processing behaviour and bolus formation were affected differently by bread and wafer leading to different taste, flavour and texture sensations. This may indicate that cross-modal interactions may play a role, since the addition of a carrier with a hard texture might impact the flavour perception of a semi-solid spread (Cherdchu and Chambers, 2014; Meinert et al., 2011; Paulsen et al., 2012). Overall, these findings corroborate the results of van Eck (2021) who observed a decrease in taste and flavour intensities of mayonnaise when it was combined with bread and potato (van Eck et al., 2021). It should be noted, however, that even though there were clear differences in the mechanical and texture properties of both carriers, no further analysis to characterize them was performed.

Lastly, it was hypothesized that TCATA provides better characterization of composite foods than TDS since participants can select multiple sensory attributes from different modalities (flavour and texture) at the same time. For the carrier-spreads combinations, the sensory attributes with highest citation proportions observed with TCATA were also significantly dominant in TDS, indicating that TDS and TCATA characterized products in a similar way. In both methodologies, peaks related to the attributes from the carrier reached highest citation proportions and dominance rate in TCATA and TDS respectively, in the beginning of the evaluation and across all spread formulations. However, it seems that TDS provides a better description of the temporal changes in sensory perception, as the sensory attributes appear and disappear above the significance line over the course of the evaluation. In contrast, in TCATA, only the attributes sticky, sweet and hazelnut showed somewhat clear peaks in citation proportions at specific moments in time. A general bell-shaped curve for all attributes was seen in TCATA peaking around the swallowing moment with limited variation in peak time between attributes. TCATA provided a more detailed product description compared to TDS. The PCAs built from the TCATA data show that the difference between the spreads disappear when they are combined with carriers (especially with wafers). Looking at the sensory trajectories built from the TDS data, they show similar trajectories for all reformulated spreads even when consumed alone, suggesting that TCATA indeed provides a better discrimination between products than TDS, which validates previous studies that have compared both methodologies (Ares et al., 2015, 2017; Nguyen et al., 2018) in single foods. Our study demonstrates that previous findings of studies comparing TCATA, and TDS can be extended from single foods to sensorial more complex composite foods which confirms our last hypothesis.

5. Conclusions

This study demonstrated that dynamic sensory perception of hazelnut chocolate spreads differing in composition was strongly affected by addition of carriers. Perceptual differences between spreads diminish when spreads are consumed with breads and wafers. These findings indicate that sensory perception of composite foods is complex, and sensory characteristics of one food are influenced by the specific properties of the other food present. Consequently, considering sensory assessments not only with consumers but also with the most frequently used accompanying foods will give a more representative sensory profile of the real consumption context. Ultimately, the use of carriers might also help in the development of healthier foods (e.g. low in calories, reduced fat, reduced sugar, reduced salt), due to organoleptic complexity of the product. Finally, TCATA and TDS both gave complementary information; while TCATA allowed to discriminate better between spreads, TDS revealed the temporality of sensations clearer.

Credit authorship contribution statement

Karina Gonzalez-Estanol: Conceptualization, Methodology, Data curation, Writing – original draft, Visualization, Investigation, Software, Validation. **Danny Cliceri:** Conceptualization, Methodology, Visualization, Investigation, Software, Validation, Writing – review & editing. **Franco Biasioli:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Markus Stieger:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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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.2022.104532.

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