Understanding the role of dynamic texture perception in consumers' expectations of satiety and satiation. A case study on barley bread.

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Abstract

Dynamic sensory perception has become of interest particularly related to consumers' affective response, however, better understanding the eating experience further than liking, taking into account how the dynamic sensory perception correlates to satiety perception becomes also very relevant. The objective of this work was to better understand satiety expectations in relation to the temporal aspects of texture perception during consumption. Eight barley bread samples were manufactured, with the same formulation, ingredients and caloric content but manipulating their texture by changing process parameters. A trained sensory panel evaluated the eight samples in triplicate, using a dynamic sensory method: Temporal Dominance of Sensations (TDS). Based on the results, four samples with well differentiated dynamic profiles were selected. These samples were also evaluated via classic descriptive analysis by the trained panel. A consumer test (n=96) was run where consumers evaluated overall liking, expected satiety and expected satiation and answered to a check-all-that-apply (CATA) question that included 23 sensory and 15 non-sensory attributes. The results showed that the samples did not present mayor differences in liking but were significantly different in their expected satiety. Results showed that in solid foods like barley breads with the same ingredients, same composition and same caloric content, the oral processing, determined by textural changes, was the driver of different expectations of satiety and satiation. Dynamic textural changes responsible for driving satiety and satiation expectations were identified. Chewiness dominance mainly in the first stages of mastication and coarseness throughout the mastication were drivers of enhanced satiety perceptions, whereas a dominant perception of dryness and crumbliness at the beginning were linked to breads less expected to be satiating. A penalty lift analysis on the CATA results highlighted *compact*, *coarse* and *heavy* as the most important drivers of expectations of satiety and satiation for consumers, while *aery/fluffy* and *not coarse* were inhibitors of those perceptions.

Keywords: *dynamic sensory perception; temporal dominance of sensations; TDS; expected satiety; expected satiation; consumers; CATA; barley bread*

1. Introduction

Overweight and obesity are major risk factors for various diseases, including diabetes, cardiovascular diseases and cancer. They are not only considered a problem in high-income countries, but also in middle- and low-income countries. From Global Health Observatory (GHO) data, in a global basis, around 39% of adults aged 18 and over were overweight in 2014; 13% were obese.

To control meal size and tackle overeating, there is a need to formulate healthy and satiating low-energy foods reaching consumers' acceptance. Satiety related perceptions include satiation and satiety; the former is process that leads to the termination of eating and therefore controls meal size, the latter is process that leads to inhibition of further eating, decline in hunger, and increase in fullness after a meal has finished. Compared with satiety, satiation is more strongly related to sensory attributes (Blundell et al., 2010; Lesdéma et al., 2016). The amount of intake of a particular food, however, is not solely governed by hedonic responses. It depends on the associations between sensory attributes and its metabolic consequences or expectations after consumption (Brunstrom & Rogers, 2009; Brunstrom, Shakeshaft, & Scott-Samuel, 2008). These expectations are thought to guide both portion size selection and actual food intake (Keri McCrickerd, Lensing, & Yeomans, 2015).

Recent studies (Brunstrom, 2014; K. McCrickerd & Forde, 2016; Wilkinson & Brunstrom, 2009) have highlighted that decisions about portion size are likely to be taken before a meal begins and that people are very good at estimating 'expected satiety' and 'expected satiation', that is, the experience of satiety is influenced more by what the person see and remembers eating, and less by what they actually ate. Brunstrom (Brunstrom, 2007; Brunstrom, 2014) stated that the expectations of satiety and satiation are highly correlated with the actual number of calories that people consume, and are learned over time. Expectations are based on the complex interaction of various parameters like energy content, volume, weight, sensory properties, oral process or 'eating topography' determined by bite size, bite rate, swallow rate, etc. (de Graaf, 2011; Forde, van Kuijk, Thaler, de Graaf, & Martin, 2013).

In human subjects, food is emptied into the duodenum for absorption at a rate of only about 10 kJ/min (Carbonnel, Lémann, Rambaud, Mundler, & Jian, 1994). This greatly constrains the opportunity for physiological adaptation and the detection of energy as a meal proceeds. To overcome this problem, people often use their prior experience to moderate intake as well as satiation. In other words, meal size is controlled by the decisions about portion size, before a meal begins. Thus, satiation might be determined by the volume of food that is consumed rather than its energy content (Brunstrom, 2011).

Texture and flavor are the important dimensions of sensory perception. Between these dimensions, texture rather than flavor, determines expected satiation (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011). From a cognitive perspective, people may think solid foods are more satiating than liquid foods, i.e. solid foods will contain more energy than liquid foods, without reflecting about their actual calories (de Graaf, 2012). Besides, texture plays a critical role in satiation or satiety through its effect on oro-sensory exposure. Due to their fluid nature, liquid foods require less oral processing time than semi-solid and solid foods, leading to reduction in oro-sensory exposure, which is important for the development of satiety related perceptions (Keri McCrickerd, Chambers, Brunstrom, & Yeomans, 2012). It is therefore essential to gain a deep understanding of how texture impacts expected satiation and satiety.

Sensory perception, however, is not a single event but a dynamic process with a series of events (Labbe, Schlich, Pineau, Gilbert, & Martin, 2009). The relation between sensations and elicited satiation is not necessarily static during consumption. For example, using milkshakes thickened with several hydrocolloids, a recent study by (Morell, Fiszman, Varela, & Hernando, 2014) showed that satiety expectations were closely related to consistency and creaminess at the start of the consumption in products of similar consistency but different dynamic perception in mouth. Thus, the effect of texture on satiety expectations is not a straightforward function of hard/soft or viscous/not viscous, but rather related to a number of factors: viscosity, food particles, the complexity of the food items, their interaction, and their influence on the temporality of the in-mouth perception (Marcano, Morales, Vélez-Ruiz, & Fiszman, 2015; Morell, Ramírez-López, Vélez-Ruiz, & Fiszman, 2015; Tarrega, Marcano, & Fiszman, 2016). To further understand the relationship between sensory perception and expected satiating effects, it is required to take into account the dynamics of perception; attributes should be assessed during the length of oro-sensory exposure time. Temporal Dominance of Sensation (TDS) is a relatively new methodology in the sensory field for describing temporal perception, first presented at the Pangborn Symposium by Pineau, Cordelle, and Schlich (2003). Likewise, TDS has proven to be useful for evaluation of the dynamics of texture perceptions during food consumption (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009; Saint-Eve et al., 2011). Traditionally, TDS results have been presented as average dominance curves, showing the proportion of attributes dominance against time (Pineau et al., 2009). TDS scores can be also calculated in order to compare with sensory profiling results (Labbe et al., 2009). For each sample, TDS scores are applied for different time intervals during the mastication to obtain a sample trajectory which shows the evolution of sensory perceptions when the sample is consumed (Lenfant et al., 2009). The number and duration of time intervals are fixed, and chosen based on TDS curves (Dinnella, Masi, Naes, & Monteleone, 2013).

This study aimed at exploring the role of texture of solid foods in consumers' perception and expectations of satiation and satiety, in particular the role of dynamic perception during oral processing, with barley bread as a case study.

2. Materials and methods

2.1. Samples

Eight barley bread samples were manufactured at Nofima's pilot bakery, using the same formulation and ingredients but manipulating the texture of the final products by changing process parameters. Samples were equi-caloric breads, prepared from standard recipes; texture was manipulated by scalding or soaking the barley, and through fermentation, as sourdough was added to some of the batches (Table 1).

In order to investigate different texture profiles, eight breads were made, based on four factors: barley type (flour or flakes), size (fine/thin or coarse/thick), treatment (soaking or scalding) and fermentation (yes or no) (Table 2). For each type of bread, six loaves were made.

For the fermented samples, 100 g of water and 100 g of wheat flour were removed from the standard recipe, and 200 g sourdough was added (see recipes in Table 1). The sourdough, 0.15 g Florapan L73, 500 g wheat flour and 500 ml water, was fermented at 25^{0}C (60% RH) overnight. Depending on soaking or scalding, the barley flour or flakes were soaked in 1000 ml of water (12^{0}C) for one hour, or 1000 ml of water

(100^0C) was added, and cooled down overnight at room temperature, respectively. During both soaking and scalding the mixture was covered with a plastic film to prevent drying. Doughs were mixed and breads baked in an industrial oven. The loaves were cooled down on a tray, and stood overnight uncovered. The loaves were sliced in a bread slicer, the ends of the loaves were discarded, and the slices from the middle part of the loaves (1.1 cm thick) were used for testing. The sliced breads were frozen, then thawed for each of the tests. Thawing was done in the same conditions for all tests.

2.2. Temporal Dominance of Sensations (TDS)

Ten assessors with previous experience in quantitative analysis and TDS took part in this study. The evaluation was conducted following the TDS approach presented in (Agudelo, Varela, & Fiszman, 2015). The assessors were firstly reminded the concept of dominant sensation at a given time during the food consumption, then tasted eight samples and listed all the dominant attributes they perceived. After that, the most frequently cited attributes were selected upon agreement among the panelists. The sensory lexicon generated for breads included eight texture attributes (Table 3) and definitions from ISO 5492:2008.

For the formal assessment, assessors were first served a warm-up sample, and then tasted the samples, served simultaneously in small plastic cups coded with 3-digit random numbers. The test was conducted in individual booths under white light with adequate ventilation. Assessors were asked to put the sample in their mouth and press “START”, subsequently selecting the dominant sensations while eating by clicking at all times one among eight attributes presented on the computer screen. When the sample was ready to swallow, they pressed “STOP” and spat out the sample. The assessors could successively select as many attributes as they wanted during the oral processing of the samples, including re-selecting an attribute more than once during the test. At all times, only one attribute was selected (the dominant one). Assessors were asked to rinse their mouth with water between samples.

2.3. Sample selection for Quantitative Descriptive Analysis (QDA) and Consumer testing

Based on the results from TDS analysis, four breads (Bread 3, Bread 5, Bread 6 and Bread 7, see Table 2) were chosen for QDA and consumer testing. These breads were selected on the criteria that they were the most different ones in term of dynamic texture profiles (see section 3.1.1). All tests were run November-January 2015-2016.

2.4. Quantitative Descriptive Analysis (QDA)

Sensory profiling was performed on four selected breads through quantitative descriptive analysis QDA (Stone & Sidel, 2004) by Nofima's trained panel. The descriptive terminology of the products was created in a pre-trial session using Breads 6 and 7. After pre-trial session lasted 1 h, the descriptors (attributes), definitions, and reference samples were agreed upon by the assessors. By the end of pre-trial, all assessors were able to discriminate among samples, exhibited repeatability during trials, and reached agreement with other members of the group. The final list was comprised of eight flavor attributes (*bitter, cloying, grainy, raw, salty, sour, sweet* and *yeast*) and eight textural attributes (*chewy, dough-like, crumbly, porous, coarse, hard, juicy* and *sticky*).

The QDA was conducted in individual booths. Two pieces of a sample were served in plastic cups coded with 3-digit random numbers, at room temperature, and in a sequential monadic manner following a balanced presentation order. The evaluation was done in two replicates and lasted 1.5 h.

2.5. Consumer test

Ninety-six consumers were recruited for the test in the southeast area of Oslo from Nofima's consumer database (51 males and 45 females, aged between 18 and 40 years). Their recruitment was based on the following criteria: consumption of coarse bread at least 2-3 days a week, not on a special diet, and neither celiac, gluten sensitive or aversive to wheat/barley. Consumers were instructed not to eat for at least 2 hours and not to use products of persistent flavours at least 30 mins before testing.

The formal assessment was performed in individual booths. Consumers took maximum 30 minutes to complete the test. At the beginning of the tasting session, the consumers were asked to rate their current level of hunger on a 100-mm line scale, ranging from "Not hungry at all" to "Very hungry". The products labeled with 3-digit codes were presented according to a sequential monadic order to balance out carry-over effects in the global data set. For each product, consumers rated their liking, satiety expectations, and answered a CATA (check all that apply) question, as follows:

Acceptance rating: "How much do you like this bread?", rated on a 9-point hedonic scale

Expected satiation: "How full do you think you would get eating this bread?" rated on a 9-point scale (1 = not at all; 9 = extremely)

Expected satiety: "For how long do you think you would feel full from this bread?", rated on a 6-point scale from 1 = "hungry again at once" to 6 = "full for five hours or longer".

CATA question: “Choose all the attributes/ terms that apply to this bread”. The CATA question included a list of 23 hedonic and descriptive sensory attributes (*good flavor, bad flavor, bitter flavor, grain/cereal flavor, sour flavor, taste of sourdough, yeast flavor, not coarse, medium coarse, very coarse; airy, chewy, compact, crumbly, doughy, soft, hard, heavy, juicy, dry, porous, sticky*) and 15 usage & attitude terms *(appealing, fibrous, health/nutritious, not appealing, satiating, suitable for breakfast, suitable for lunch, suitable for lunch pack, suitable for dinner, suitable for supper, unhealthy, “everyday” bread, weekend bread, would buy, would not buy*). The order of terms was randomized within the two groups (sensory and usage), between products, and across assessors.

2.6. Data analysis

The TDS data were collected with EyeQuestion (Logic8 BV, The Netherlands) and presented as TDS curves with standardized times (from T0 to T100). Briefly, there are two main lines that assist the interpretation of dominance curves in a TDS plot, ‘‘chance level”, with value P_0: the dominance rate that an attribute can obtain by chance, and ‘‘significance level”, with value P_s: the minimum dominance rate to be reached for the attribute occurrence to be considered as significantly higher than chance level P_0 (Pineau et al., 2009). In this study, standardized evaluation times (from T0 to T100) were split into smaller time periods with three intervals (T0-T40: beginning; T41-T80: middle; T81-T100: end) for analyzing the TDS scores (Dinnella et al., 2013). TDS scores, for each time interval, were then defined according to Eq. (1) (Labbe et al., 2009).

$$SCORE = \left(\sum_{Scoring} Proportion \times Duration \right) \Big/ \sum_{Scoring} Duration \qquad (1)$$

Multiple Factor Analysis (MFA) was applied to the TDS scores. Scores and loadings were plotted from the first two components to assess sample differences and/or similarities in sensory attributes with corresponding time intervals.

A Principle Component Analysis (PCA) based on standardized data was performed to show sample trajectories in the sensory space over the mastication duration. The variables were sensory attributes, whereas the objects were samples at different time intervals (T10-T100). In the PCA map, each trajectory was displayed by linking the ten points of time intervals corresponding to the same sample (Lenfant et al., 2009).

For QDA data, the estimated means were calculated for each of the sensory attributes using a General Linear Model with sample as a fixed effect, and a random subject effect. Differences between the attributes were assessed by ANOVA and a summary plot of all sensory differences was prepared to account for differences between samples.

Liking scores that differed between the breads were compared using one-way ANOVA with Tukey's post-hoc test. Segments of consumers were identified using Hierarchical Clustering Analysis (HAC; Euclidean distance, Complete-linkage criterion).

Cochran's Q test was carried out on the CATA results in order to identify significant differences between samples for each of the attributes. Penalty-lift analysis was also performed on consumer responses to determine the effects of the presence and absence of CATA attributes on expected satiation and satiety (Williams, Carr, & Popper, 2011).

All analyses were carried out using XLSTAT, Version 2016 (Addinsoft).

3. Results

3.1. Sensory profiling with the trained panel

3.1.1. Dynamic texture perceptions via TDS

The TDS curves were obtained by plotting the dominance rate of each of the evaluated attributes across the panel for the different points of the eating period (Pineau et al., 2009). Since the duration of the consumption of the breads up to swallowing differed from one assessor to another (total evaluation time), the time scales also differed (Lenfant et al., 2009). In order to take this into account, the data from each assessor was normalized according to the individual mastication durations, such that the first scoring would be at T=0 and the last scoring would be at T=100. As a result of the normalization, the X-axis of the TDS curves corresponds to the normalized time (% of consumption time, from T0-T100) and the Y-axis to the dominance rate or frequency of selection of that attribute at a particular point in time (%).

Fig. 1 shows the smoothed TDS curves for the four breads showing the most distinctive temporal profiles. The other four TDS plots considered for sample selection are not presented here, interested readers should contact the authors for more info. For these four breads, TDS curves were very different both in frequency and sequence of attributes for all the breads, as per the objective of the sample selection. It was evident that texture attributes dominance rates significantly changed with the varying processing parameters. For Bread 3 and Bread 5, the attribute *chewy* was perceived as dominant during the first part of the consumption (T0-T20), and *sticky* was dominant during the end of the oral processing (T80-T100). In contrast, the dominant attributes characterizing Bread 6 and Bread 7 were *dry* in the beginning of the consumption (T0-

T30) and *juicy* in the end (T80-T100). It is noteworthy that the differences between the four samples were maximized in the middle of the oral processing period. Thus, Bread 3 presented a high dominance rate value for *Dough-like* between T30 and T80, while Bread 5 was first *soft* and then *juicy* in this period. *Soft* and *Juicy* were also significant for bread 3, but was predominantly *dough-like* in the middle period; conversely, this attribute barely surpassed the significance level in Bread 5. Similarly, Breads 6 and 7 had comparable dynamic profiles in the beginning and end of the mastication, but were considerably different in the middle. In Bread 6, only *crumbly* was significantly dominant from T30 to T80, while Bread 7 was described as dominantly *chewy* and *coarse* from T20 to almost T80, when *sticky* and *juicy* became dominant (Fig. 1).

3.1.2. Static descriptive analysis of bread texture via QDA

QDA was run in eight flavor and three texture attributes. Main differences among the four samples were on the textural profile. Regarding flavor, there were minor perceptual differences in saltiness and sourness. This is consistent with the recipes and experimental design (Tables 1, 2) which varied process parameters but kept the ingredients constant.

Fig. 2 shows the averages for all the textural attributes in the QDA test, as highlighted by the ANOVA and Tukey tests. All the attributes help discriminating among the samples. Bread 7 was the most distinct sample, significantly more *porous, hard, coarse* and *chewy* than all the other samples. Bread 3 was very similar to Bread 5 from a static point of view, with no significant differences in any of the textural attributes. They were described as low in *porosity*, *coarseness*, *chewiness* and *crumbliness* and high in *stickiness*, *juiciness* and *doughiness*. Bread 6 and Bread 7 were not significantly different in four out of eight attributes: *juicy*, *sticky*, *crumbly* and *doughy*.

3.2. Overall liking, expectations of satiation and satiety

Table 4 shows the average results for the overall population participating in the consumer test: liking and expectations of satiation and satiety. ANOVA did not show significant differences in overall liking between the four products. This indicates that consumers on average did not like any of the products more than the others. In terms of expected satiation, Bread 6 was the bread rated as to be the least satiating, whereas the difference was not significant among Bread 3, Bread 5 and Bread 7. Expectation of satiety followed a similar trend, but with Bread 7 middle way between the two groups; expected satiety scores for Bread 6 and Bread 7 (3.1 and 3.4, respectively) were generally lower than those of Bread 3 and Bread 5 (from 3.6 to 3.7). In the present study, the fact that consumers on average did not favor one sample over the others makes it easier to conclude about satiety and satiation expectations based on the textural changes and the dynamics of perception. It is necessary, however, to look into the liking into more details to see if there were groups of consumers with different liking patterns and if so, different satiety expectations patterns from the total consumer sample.

When Cluster Analysis was applied to preference data, three segments of consumers were initially detected, including cluster 1 (n=60), cluster 2 (n=29) and cluster 3 (n=7). The focus here will be on clusters 1 and 2, as the third is too small to conclude on. Cluster 1 did not present significant differences between bread samples in product overall liking ratings (p-value=0.427).

In cluster 2, significant differences in hedonic score were detected among products (p-value=2.8e-4). Bread 7 was considered as the best liked (average score = 5.0), followed by Bread 6, Bread 5 and Bread 3 with no significant differences between these last three. In general, trends in this cluster did not differ much from the total consumer sample in terms of satiety and satiation expectations, these consumers just discriminated less in general. However, for these 29 consumers like for the total sample, Bread 6 was still the one rated as less satiating based on their expectations.

3.3. Texture perception, oral processing, and consumers' expectations of satiety and satiation

As per the previous sections, results showed that the formulated bread samples, with no differences in ingredients, composition and caloric content, and no large differences in acceptability levels, have been perceived by consumers as different in expected satiety and satiation. The hypothesis is that the main differences driving this perception are based on the oral processing and the perceptual textural differences during the eating of the samples. In the next two sections, the focus will be on the understanding of those differences, based on the dynamic perception as assessed by the trained panel (TDS) and the consumers' perception of the products as per the CATA results.

3.3.1. Role of dynamics of perception in the expectations of satiety and satiation

In order to gain further understanding of the dynamics of perception, TDS standardized time was split into three intervals of the oral processing period (*beginning*, *middle* and *end*). The number and duration of time intervals did not affect the relative differences among products (Dinnella et al., 2013). The interval sizes have to be short enough to glean temporal information and large enough to capture what the panel as a whole perceived over the bread. Therefore, based on the observation of the TDS plots, T0-T40, T41-T80 and T81-T100 were selected for the beginning, middle and end intervals, respectively.

MFA was applied on the time intervals data of the TDS, in order to study the relationships between the samples and the temporal dynamic attributes during the three stages of the mastication, and to being able to plot them together with the consumers' expected satiety and expected satiation results (Fig. 4). The first dimension opposed products in terms of *dough-like* dominance perception (from beginning to end of consumption), juiciness at the beginning and middle (*b.juicy, m.juicy),* and stickiness perception in the middle of the eating period (*m.sticky*). Breads 3, 5 and Breads 6, 7 were located on the right and left extremes of the plot, respectively. Bread 5 and Bread 3 were grouped very close together in the MFA perceptual map, described as dominantly *dough-like* from beginning to end of the consumption, dominantly *juicy* and *sticky* in the *middle, and soft* in the *beginning.*

Bread 6 was characterized by being dominantly *crumbly* (both in the beginning and middle), and *dry* in the beginning, whereas Bread 7 presented high dominance rates for *coarse* (during the whole consumption) and *m.chewy* (dimension 2). However, both breads were perceived *dry* in the beginning and *juicy* in the end of consumption (dimension 1).

In the correlation map (plot on the right in Fig. 4), expected satiation and expected satiety were plotted as supplementary attributes. The results indicated that the expectations were driven by *chewy* dominance (mainly in the beginning of consumption, but also partially during the rest of the mastication) and negatively correlated to *crumbly (*beginning and middle*)*, *b.dry* and *e.juicy*. *Chewiness* and *coarseness* dominance differentiated bread 7 from bread 6, which was expected to be less satiating. A more satiating barley bread would then be either dominantly *coarse* throughout the mastication and *chewy* in the middle stages, or else dominantly *chewy*, *sticky* and *dough-like* throughout the mastication; on the contrary, a barley bread which is not perceived as *chewy* is dominantly *crumbly* in the first stages of the mastication and is *dry* in the beginning, will be perceived as less satiating. *Juiciness* might be a driver of higher expectations of satiety in the beginning and end of the eating period, but not in the end.

3.3.2. CATA question. Drivers of expected satiation and satiety

Of the 14 texture attributes listed in the CATA questionnaire (*medium coarse* and *very coarse* were considered *coarse*), Cochran's Q test (Table 5) showed that 10 of the attributes presented significant differences between the samples (all except for *dry, juicy*, *soft* and *chewy*).

The Correspondence Analysis result displays the differences and similarities between the products in a bi-dimensional space (Fig. 5). The first dimension (87% of total variability) separated products into two groups, particularly, group 1 (Bread 3 and Bread 5) was located on the left, group 2 (Bread 6 and Bread 7) on the right. This position was in line with the product discrimination based on TDS results (Fig. 4). Bread 3 and Bread 5 were perceived as *doughy*, *compact*, *hard* and *heavy*. Breads 6 and 7 were positioned on opposite sides of the second dimension (12% of total variability). On the negative side of dimension 2, Bread 7 was considered as *coarse* and *porous*, *aery/fluffy*. Bread 6, on the positive side of dimension 2, was particularly described as being *crumbly*, *not coarse, porous* and *aery/fluffy*. Note that product Bread 6 was the one expected to be the least satiating (Table 4), suggesting the attributes *crumbly* and *not coarse* would be negative drivers for the expectations of satiety in this sample set, in agreement with the findings on the temporal data reported in section 3.3.1. Bread 7 was also perceived as *porous* and *fluffy* by consumers, but *coarseness* has driven the expectations of satiety in this sample. This is in line with the results obtained with the

TDS data and indicates that a high *coarseness* could be a driver of enhanced satiety expectation.

In order to examine the impact of different attributes on satiation and satiety, a penalty-lift analysis was performed based on the CATA data, to determine the effects in the expectations of satiating effects with the presence and absence of CATA attributes. This approach has been used in the past to study the effects on liking scores of checked and non-checked attributes (Ares, Dauber, Fernández, Giménez, & Varela, 2014; Meyners, Castura, & Carr, 2013), and to relate CATA answers to expectations of satiating capacity (Tarrega et al., 2016). In the present study, satiety (or satiation) ratings were averaged across all observations (consumers and products) in which the attribute was used to characterize the product, and across those observations for which it was not. Calculating the differences between those averages one can estimate the change in satiety expectations (or satiation) due to this attribute being checked versus not checked in the CATA questions.

Fig. 6 shows the results of the penalty-lift analysis, indicating the attributes that had positive or negative impacts on the expectations of satiation and satiety.

Compact, *coarse* (merged from *medium coarse* and *very coarse*) and *heavy* were found to be the most important drivers of expectations of satiety and satiation, as highlighted by the attributes evaluated in the CATA question. They increased the expected satiation by almost up to 1 point on the 9-point scale, and satiety expectations up to 0.5 point on the 6-point scale when checked, as compared to being not checked. The results also reveal that *aery/fluffy* and *not coarse* were inhibitors of expected satiation and expected satiety by suppressing the expectations about 1 point and 0.5 point, respectively. These results are in agreement with some of the findings from the dynamic perception evaluated via TDS. *Chewy* and *doughy*, that were suggested as important drivers of the expectations by the TDS results, were not highlighted by the penalty-lift as drivers of consumer perception. However, looking into the CATA count table one could see that consumers perceived these attributes as less associated to Bread 6, which is consistent with these results. Further research should relate to the information about an ideal product, including sensory, consumer preferences, expectations of satiation and satiety; the evaluation of an ideal satiating bread could enable the identification of what underlies consumer perceptions in a further detail.

4. Discussions

4.1. Static vs. dynamic descriptive profiles

Compared to QDA results (Fig. 2), the individual TDS plots (Fig. 1) and the product trajectories defined by the temporal data (Fig. 3) highlight some interesting key differences that allowed a better discrimination among the four samples under study. QDA scores are only an integration of all the changes that have occurred during the mastication process, not pointing out the dynamic aspects of in mouth texture perception, as highlighted by (Lenfant et al., 2009) when proposing the concept of sensory trajectory. Taking for example Bread 6 and Bread 7, they were described as very similar in static profiles but not quite similar from a dynamic point of view, as per the observation of their TDS plots, both were perceived as *dry* at the beginning and *juicy* and *sticky* at the end, but the perception in the middle period of the oral processing was characterized by different dominant attributes. For Bread 6, *crumbly* was dominating during the middle of consumption. By contrast, *coarse* and *chewy* were dominant for Bread 7. These differences were also highlighted by the product trajectory plot, where both samples start as *dry* and move in the perceptual space towards different directions, to then “meet again” in the *sticky, juicy* region of the plot.

In addition, some attributes were also described very differently between QDA and TDS approaches. *Juicy*, for example, presented very similar intensity ratings for the four samples in the QDA; however, the individual TDS plots showed that *juiciness* was dominant at different points of the mastication, for Breads 3 and 5 it dominated in the middle of the eating period and remained significant until the end, while for Breads 6 and 7 it only became significant and dominant at the end. Looking at the trajectory plot, all products followed a distinct path, and “met” at the end of the oral processing in the *juicy* and somehow *sticky* and *doughy* area. One explanation for this is that all products in mouth need to be diluted and comminuted until a “swallowing threshold” is reached (Witt & Stokes, 2015). In this case, *juicy* might be the attribute which was the signal for readiness to swallow, such as all products were perceived the same way at the end of consumption. For *chewy*, QDA results indicated that Bread 7 was rated the most intense, significantly different from Bread 3, Bread 5 and Bread 6. Nevertheless, Bread 7 was not particularly high in *chewy* dominance throughout its eating period, while Breads 3 and 5 showed dominance peaks at the beginning of the consumption for this attribute. Specifically, while *chewy* was strongly linked to Bread 3 and Bread 5 at the beginning, it only linked to Bread 7 at the middle of consumption, as highlighted in the trajectory plot. This implies that the product discrimination based on static profiles might not figure out the actual textural differences as perceived throughout the eating experience. Due to the dynamic nature of sensory perceptions, TDS, rather than QDA method, seemed to get a more detailed description of the actual textural differences between the products.

4.2. Expectations of satiety and satiation and Liking

The results show the differences in evaluation between expectations of satiation and satiety. This might be due to the nature of each concept, satiation was mostly influenced by sensory attributes, whereas satiety was not only correlated to sensory but also cognitive, post-ingestive and post-absorbative (Blundell et al., 2010) so it could be more difficult to measure it based on expectations only. Furthermore, the difference in scaling might have influenced, as expected satiety was measured in a 6-point scale, with less discriminating capacity than the 9-point used for measuring expected satiation. Liking is also very much correlated to expected satiety and portion size determination (Blundell et al., 2010). Liking and pleasure, linked to sensory specific satiety, might be what guide humans to eat balanced, varied meals in macronutrient and micronutrients without nutritional knowledge, however liking only does not predict when a meal ends (Møller, 2015).

4.3. Oral processing and expectations of satiety and satiation

In a previous work, Tarrega et al. (2016) found that attributes associated to oral processing, *sticky* and *chewy*, were not influential on expectations of satiation and satiety for yogurts with pieces, but semi-solid and solid samples could be perceived differently in terms of satiating effects, as liquids do not necessarily elicit the same brain responses as solids with regards to oral stimuli (Tarrega et al., 2016; Teff, 2010).

Ferriday et al. (2016) found that unmodified meals consumed to a fixed portion with variations in oral processing (fast/slow) affected fullness, so the modification of the oral process could also impact meal size. These authors suggested modifying food form to encourage increased oral processing that help to nudge consumers to manage their food consumption. Results from Morell et al. (2014) indicated the same, as they found that creaminess at the beginning of the consumption of smoothies with different thickeners, influenced satiety expectations.

In this study, results show that in solid foods like barley breads with the same ingredients, same composition and same caloric content, the oral processing, determined by textural changes, is the driver of different expectations of satiety and satiation. This has direct practical implications, and suggests clear directions for potential process changes to increase satiety perception in the case under study (barley bread). In addition, expectations of satiation and satiety were perceived differently although liking was similar for all breads. This supports the hypothesis that the expectations were mostly determined by the dynamic sensory perception of texture.

5. Conclusions

This paper aimed at understanding consumers' satiety expectations on barley breads in light of their temporal texture profiles. Results showed that in solid foods like barley breads, with the same composition (same ingredients) and same caloric content, the oral processing, as determined by textural changes, was an important driver of different expectations of satiety and satiation.

Temporal Dominance of sensations (TDS) proved useful for highlighting product discrimination of similar corresponding descriptive properties in this sample set. *Chewiness* dominance, mainly in the first stages of mastication, and *coarseness* throughout the mastication were drivers of enhanced satiety perceptions, whereas a dominant perception of *dryness* and *crumbliness* at the beginning were linked to breads less expected to be satiating.

The penalty lift analysis on the CATA results highlighted *compact*, *coarse* and *heavy* as the most important drivers of expectations of satiety and satiation for consumers, while *aery/fluffy* and *not coarse* were inhibitors of those perceptions.

From a practical perspective, *compact*, *coarse* and *heavy* might be the most advisable properties to pursue for obtaining an enhanced expectation of satiation and satiety in barley breads.

In general, more research will be needed to generalize these findings for other solid and semi-solid products; nevertheless, the management of texture looks as a promising way to modify product properties and create more satiating foods that could reduce food intake, in a world where obesity is a huge concern.

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Table 1. *Bread recipes.*

Ingredient	With sourdough (g)	Without sourdough (g)
Wheat flour	1300	1400
Barley	600	600
Salt	30	30
Active yeast	20	20
Water for soaking or scalding	1000	1000
Water	400	500
Sourdough	200	-

Table 2. Experimental design for baking process.

Sample	Type	Size	Treatment	Fermentation
Bread1	Flour	Fine/thin	Soaking	No
Bread2	Flakes	Fine/thin	Scalding	No
Bread3	Flour	Fine/thin	Scalding	Yes
Bread4	Flakes	Coarse/thick	Scalding	Yes
Bread5	Flour	Coarse/thick	Scalding	No
Bread6	Flakes	Fine/thin	Soaking	Yes
Bread7	Flour	Coarse/thick	Soaking	No
Bread8	Flakes	Coarse/thick	Soaking	Yes

Table 3. Texture attributes for the breads in the TDS test.

Terms	Definitions
Chewy	mechanical textural attribute related to the amount of work required to masticate a solid product into a state ready for swallowing
Coarse	geometrical textural attribute relating to the perception of the size, shape and amount of particles in a product
Crumbly	mechanical textural attribute related to cohesiveness and hardness and to the force necessary to break a product into crumbs or pieces
Dough-like	describes a solid or semi-solid product containing small, even cells filled with gas (usually carbon dioxide or air) and usually surrounded by soft cell walls
Dry	surface textural attribute that describes the perception of water absorbed by or released from a product (surface attributes)
Juicy	surface textural attribute that describes the perception of water absorbed by or released from a product (body attributes)
Soft	mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of a product
Sticky	mechanical textural attribute relating to the force required to remove material that sticks to the mouth or to a substrate

Table 4. Effect of product on overall liking, expectations of satiation and satiety.

	Liking	Expected satiation	Expected satiety
Bread3	5.1^{a}	5.8^{a}	3.6^{a}
Bread5	5.1^{a}	5.8^{a}	3.7^{a}
Bread6	5.0^{a}	4.6^{b}	3.1^{b}
Bread7	5.5^{a}	5.3^{a}	3.4^{ab}

Different letters in the same column indicate statistical differences ($p < 0.05$) among the products.

Table 5. Cochran's Q test for each attribute for the four breads.

Attributes	p-values	Bread3	Bread5	Bread6	Bread7
Compact	0.000	0.69^{b}	0.67^{b}	0.15^{a}	0.17^{a}
Crumbly	0.004	0.06^{a}	0.13^{ab}	0.23^{b}	0.13^{ab}
Doughy	0.000	0.43^{b}	0.39^{b}	0.20^{a}	0.20^{a}
Dry	*0.065*	*0.29^{ab}*	*0.33^{ab}*	*0.40^{b}*	*0.23^{a}*
Heavy	0.000	0.43^{b}	0.38^{b}	0.03^{a}	0.15^{a}
Juicy	*0.436*	0.29^{a}	0.27^{a}	0.20^{a}	0.26^{a}
Soft	*0.120*	0.38^{a}	0.37^{a}	0.46^{a}	0.31^{a}
Porous	0.000	0.05^{a}	0.09^{a}	0.25^{b}	0.26^{b}
Sticky	0.000	0.45^{b}	0.35^{b}	0.18^{a}	0.29^{ab}
Chewy	*0.066*	*0.23^{a}*	*0.23^{a}*	*0.10^{a}*	*0.19^{a}*
Hard	0.042	0.07^{a}	0.07^{a}	0.01^{a}	0.02^{a}
Aery/fluffy	0.000	0.09^{a}	0.15^{a}	0.63^{b}	0.64^{b}
Not coarse	0.000	0.21^{a}	0.25^{ab}	0.40^{b}	0.12^{a}
Coarse	0.003	0.41^{a}	0.48^{ab}	0.37^{a}	0.60^{b}

Figure Captions

Fig. 1. TDS plots for Bread 3 (a), Bread 5 (b), Bread 6 (c) and Bread 7 (d).

Fig. 2. Average intensities of the textural attributes in the QDA.

Fig. 3. TDS trajectories. (B3, B5, B6 and B7 are Bread 3, Bread 5, Bread 6 and Bread 7, respectively)

Fig. 4. Representation of the bread samples (*left*) and the dynamic sensory attributes (TDS data, *right*) across all oral processing intervals on the first two dimensions of the MFA. (*b.*, *m*. and *e.* were the notation of beginning, middle and end time intervals; expected satiety and satiation were plotted as supplementary variables)

Fig. 5. Representation of the CATA texture attributes and products (Correspondence Analysis).

Fig. 6. Penalty-lift analysis of expected satiation (left) and expected satiety (right).