Food Quality and Preference 119 (2024) 105209

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Use of face reading to measure oral processing behaviour and its relation to product perception

Aikaterini Katsikari *, Mads Erling Pedersen, Ingunn Berget, Paula Varela

Nofima AS, P.O. Box 210, 1431 Ås, Norway

ARTICLE INFO

Keywords:
Textural properties
Automatic measures
Oral processing
Satiety
Consumer acceptance
Dynamic profile

ABSTRACT

Food texture can influence sensory perception and eating behaviour; it can be managed to affect intake, by inducing higher expected satiety and satiation, and eventually reducing overeating. The objective of this work was to assess face reading as an automatic measure of oral processing behaviour of products with different texture modifications, aimed at reducing intake. Three oat breads with different textural properties were used as a case study. A trained panel used Temporal Dominance of Sensations to describe dynamic sensory profiles of the breads and were simultaneously video recorded; the videos were analysed by FaceReader (intake, chewing motions, chewing period). The parameters extracted through face reading showed significant differences among the breads in duration of chewing period and number of chewing motions, which can be interpreted together with the TDS results. A consumer test (n = 135) was conducted on the breads, where participants evaluated overall liking, expected satiation and satiety, and answered a Check-All-That-Apply question including sensory and non-sensory attributes. Results indicated that the samples were significantly different in terms of liking, expected satiation and satiety and that consumers described samples in CATA question in line with the panel. Results interpreted together allowed the identification of the dynamic textural properties responsible for enhancing satiety and satiation expectations. Methodological implications are discussed throughout the paper. The novelty of the study is to show that automatic measures of oral processing behaviour by face reading, can be linked to self-reported explicit measures of satiety, opening the door to larger studies, unfeasible using manual annotation.

1. Introduction

Chronic increase in food energy consumption is associated with a long-term imbalance between the ingested food and the energy expended, eventually leading to a prevalence of overweight and obesity and is associated with non-communicable diseases (Bray, 2004; Levesque, 2018; Rimmer, 2018). This constitutes a burden to individuals, the public health system, and the governments, along with food producers, are making a combined effort to invest in food products that keep high levels of nutrients while reducing energy density (Rimmer, 2018).

Most research emphasises on reducing the portion sizes and/or diminishing additive nutrients such as salt, sugar and fat (Bolhuis & Forde, 2020). Recent evidence, though, pinpoints oral processing (e.g., chewing, size of a bite, texture) and its role in affecting satiation and satiety and subsequently influencing food energy intake. An alteration in oral processing, for example, a longer chewing period, may affect the timeline of satiety signals to be activated and terminate the meal (Hogenkamp & Schiöth, 2013). This was explained by Brunstrom and collaborators (2011a, 2011b) that shown that although meal size is primarily regulated by physiological and psychological signals of satiation, the decisions about portion size are taken before a meal, influenced by expectations of fullness and hunger relief from foods, playing a significant role in determining energy intake. These expectations (expected satiety and expected satiation) are driven by physical characteristics of food and learned behaviours, influencing portion control in meal consumption, and related to actual satiation and satiety (Brunstrom, 2011; Brunstrom et al., 2011). Food texture perceived in the oral cavity is dependent on the behaviour of the specific food when chewed and physically transformed by the oral organs and saliva throughout the process of mastication. After the intake, food is broken down into smaller pieces, adapted to body temperature, and mixed with saliva for hydration to finally form a bolus ready to swallow. During the dynamic process of mastication, the mouth is constantly perceiving signals about texture changes and adapting accordingly to the food changing structure

* Corresponding author.
E-mail address: katerina.katsikari@nofima.no (A. Katsikari).

https://doi.org/10.1016/j.foodqual.2024.105209
Received 7 December 2023; Received in revised form 23 April 2024; Accepted 28 April 2024
Available online 29 April 2024

and the changing individual's perception. Thus, different chewing behaviours influence how individuals perceive food texture; those with shorter chewing cycles focus more on initial properties like hardness compared to those with longer chewing periods (Lenfant et al., 2009). Hence, texture affects satiety expectations in a non-static way, further than hard or soft; food texture is also about properties such as viscosity, particles of food, complexity of the foods, how they interact with oral perception through time of mastication (Morell et al., 2014; Nguyen & Varela, 2021; Nguyen et al., 2017).

Food structure can influence the balance of energy and nutrient intake. Reduced need for intense chewing and lubrication may increase both palatability and eating rate, and by that trigger higher food intake (Bolhuis & Forde, 2020). Such modifications of food structure can be used as a tool for vulnerable populations, such as elderly consumers; changes in masticatory function, along with physiological alterations in appetite, make it harder for them to maintain energy and nutrient sufficiency (Ketel et al., 2020).

Food sensory cues are responsible for eating preferences and patterns, selection of portions and satiation before and throughout consumption behaviour. For example, evidence shows that a slower eating rate can have a reduction in *ad libitum* energy intake. A bite reduced in size and an increased chewing period of a bite, along with an extended oral exposure time, can lead to lower energy intake (Teo et al., 2022). Changes in eating rate based on textural properties have been shown to affect the speed of total consumption; oral processing reactions get adapted to the structural food properties; for instance, a soft and less chewy food can be consumed comparatively faster than a hard, chewy and high in viscosity food (Forde et al., 2013). The sharpest differences depend on the different forms of food, from liquids to semisolids and solids (Teo et al., 2022). For example, a food that can be quickly consumed (like soup) will not be perceived as satiating compared to a solid food that will be slower consumed, leading to overconsumption. Therefore, the speed that a food item can complete the mastication cycle is related to satiating capability and more exactly to the rate of oral processing (De Wijk et al., 2019).

Most methods of analysing oral processing behaviour (e.g., intake, chewing motions, swallowing) are dependent on human explicit procedures (Bolhuis & Forde, 2020). Although accurate and standardised methods, they can lack objectivity and feasibility as they are repetitive, time-consuming, and unable to be practised in large studies. Therefore, alternative automated methods of measuring oral processing behaviour are currently being applied (Tufano et al., 2022). Especially when applied in consumer's natural environment, these measurements may provide more accurate information about their preferences in food than the more traditional self-report, and give additional value to the evaluation (e.g., detect emotional response, record interactions in a social environment) (De Wijk et al., 2019). Video recordings of oral processing behaviour can provide objective, accurate and automated measurements. In their review, Tufano et al. (2022) report different types of measuring oral processing behaviour, some more promising than others. However, advancements are still needed to standardize procedures in terms of accuracy of detection, usability, and computational requirements. Thus, research is still needed in this area, to allow for large eating behaviour studies where manual annotation is unfeasible.

The present study has a methodological focus, aiming at assessing the application of face reading, as a simple, automatic measurement to better understand oral processing behaviour. Results from face reading measurements are related to preferences and satiety expectations of products with controlled texture modifications aiming at reducing intake. A case study in oat breads with different textures would be utilised as proof of principle.

2. Materials and methods

For relating different aspects of sensory perception, acceptance and eating behaviour, the following methods were applied and will be described in detail below: a sensory dynamic description with a trained panel (via TDS) and simultaneous measurement of oral processing behaviour via face reading. Face reader is used as a non-invasive measure where assessors are video recorded while eating, and automatic counting of the oral processing behaviour parameters can be attained with the FaceReader software. This aspect is combined with self-reported measures from consumers, such as liking, expected satiety perception and product description via CATA (check-all-that-applies). Consumers were also video recorded, but these automatic measures are not included in the present work due to poor quality of the data, more methodological details are included in the discussion section.

2.1. Samples

Two types of oat bread samples were manufactured at Nofima's pilot bakery, one enriched in beta-glucan fibre (hereby called "BetaGlucan") and a control model one containing wholegrain wheat fibre (hereby called "Model"), formulated to have equal calories, starch, and fat. Both were part of an EU funded project, CarbHealth (Joint Programming Initiative "A Healthy Diet for a Healthy Life" and ERA-NET Cofund HDHL INTIMI), and were formulated for a clinical trial, to explore potential mechanisms and relations of bread intake with glycemic control and weight management (Hjorth et al., 2022). BetaGlucan bread consisted of rapeseed oil 0.7 %, dry yeast 0.7 %, salt 1.0 %, sieved white wheat flour 21.9 %, water 53.8 %, Swedish oat powder 21.9 % and coatec sorbic acid (E200) 0.05 %. Model bread consisted of rapeseed oil 4.7 %, dry yeast 0.6 %, salt 1.0 %, sieved white wheat flour 18.7 %, wholegrain wheat flour 37.5 %, water 37.5 %, and coatec sorbic acid (E200) 0.05 %. The third sample included was a commercial Norwegian oat bread (hereby called "Commercial"), bought in a local supermarket and made with water (29 %), wheat flour (21 %), oatmeal (18 %), whole wheat flour (17 %), oat bran (9 %), wheat gluten (3 %), yeast, salt, wheat sourdough (wheat flour, water, acidity regulators (E 270 vegetable, E 260), starter culture, emulsifiers (E 472 plant-based, E 471 plant-based), rapeseed oil, fully hardened rapeseed oil, vitamin D yeast, flour treatment agent (E 300), fully hardened coconut oil. When assessing, for standardization purposes, the slices of breads were cut into the size of a bite by a stainless cylinder, including both the crumb and part of the crust. Samples were presented into plastic containers with three-digit codes marked on them and covered with metal lids on top for the breads not to get dry.

2.2. Face reading data collection

For testing with the trained panel and the consumer test, videos were recorded for every participant; were then imported on FaceReader 9 software (by Noldus Information Technology) to collect data regarding the oral processing behaviour by analysing the intake (when food enters the mouth), the chewing motions (how many chews for every consumption until forming a bolus ready to swallow) and the duration of chewing period (the period from the moment of intake until swallowing). All the above analysis and marking of the consumption incidences was automatically extracted by FaceReader. The panel videos were recorded with Lenovo 500 FHD web cameras installed on a shelf in each sensory booth. They were adjusted to each panellist and recalibrated after the test trial to achieve the best possible results. Different cameras (Razer Kiyo Pro) were used with the consumers.

2.3. Protocol

Based on internal trials, the following protocol for analysing oral processing behaviour with the use of FaceReader was developed (methodological issues are further discussed in section 4).

A time gap, marked as "unknown", at approximately 3 s of period time was observed in the beginning of each video analysis on FaceReader. Within this time, the software is calibrating the face's features and marking facial action units. Consequently, in sensory testing, the video recordings were planned to start 3 s before the intake and lasted until the individual felt ready to spit out the sample (equivalent to the swallowing point). In consumer testing the recording started 10 s before the intake; the prolonged idle time brings the participant to the most neutral mode possible before the actual stimuli, as recommended by the face reader manufacturer (Noldus).

In the pilot trials it was observed that when FaceReader does not recognise the food intake, then the whole chewing process is not recorded. As a result, the panellists were asked to make clear and not hasty movements when bringing the sample close to the mouth for intake. They were also instructed to keep a constant 20 cm distance from the table while remaining in a still position; it was ensured that they could still reach the keyboard and mouse from that distance.

For FaceReader to recognise and analyse food intake and chewing process, the camera must see the participant's upper body. The participant should be in a straight posture, keeping a specified distance from the camera and table and facing the camera while the process of food intake takes place. The cameras were adjusted to each panellist during the pre-tests and recalculated after the first trial to achieve the best possible results.

2.4. Sensory testing

Eight trained panellists evaluated each sample in standardised individual booths in accordance with ISO standards (ISO 8589, 2007). A TDS test was conducted in parallel with a face video recording during the event of sample consumption. Three replicates of samples were coded with random 3-digit numbers and presented in a balanced, rotated order (following Williams Latin Square).

Temporal Dominance of Sensations (TDS) is a methodology to describe dynamic sensory perception (Pineau et al., 2003) A list of attributes, randomised between assessors, is presented to the panel, and with the task to choose which one of the attributes is dominantly perceived at each time. During the test, the assessor identifies the dominant sensation and then picks another one, in sequence. Results are presented as TDS curves, the dominant rates of attributes (Y-axis) against standardised time (X-axis) for each sample (Ares & Varela, 2014; Labbe et al., 2009; Pineau et al., 2009). The list of the attributes at TDS was randomised between assessors. The focus was on the investigation of texture attributes of the three breads, based on ISO standards (NS-ISO 5492) for sensory standards (Table 1).

A warning message appeared just before TDS to remind the panellists about the countdown of 3 s: "On the next page: Remember to wait for the countdown to complete before taking the sample in your mouth". That time was used to calculate the facial features in the neutral state from FaceReader. The resulting video file lasted from the beginning of the 3-second countdown until the endpoint of the assessment when the panellist clicked "STOP".

2.5. Consumer testing

The protocol was registered in the Norwegian Office for data protection (Sikt), following the standards of the General Data Protection Regulation (GDPR) of the Regulation (EU) 2016/679 for data privacy laws across Europe. Furthermore, the ethical committee at Nofima approved the procedure. The consumer test was conducted on three consecutive days in April 2022.

One hundred and thirty-six consumers were recruited for the test in the area of Ås, in Norway, from Nofima's consumer database and through the online platform Facebook. 52 participants identified themselves as males, 82 as females, and 1 person chose "other"; all were aged between 18 and 79 (with a mean age of 36.7 years old). The recruitment criteria were age (adult population), frequent bread consumer, no allergies, not being on a special diet, and not being gluten sensitive or intolerant.

Table 1
Texture attributes and their definition used in the TDS test according to ISO standards (NS-ISO 5492).

Term	Definition
Softness	Mechanical textural attribute relating to the force required to achieve a given deformation or penetration of a product. Soft: low level
Toughness	Mechanical textural attribute related to cohesiveness and to the length of time or the number of chews required to masticate a solid product into a state ready for swallowing. Tough: high level
Juiciness	Surface textural attribute which describes the perception of water absorbed by or released from a product. Juicy: high level
Fibrous	Geometrical textural attribute relating to the perception of the shape and the orientation of particles in a product. Fibrous: long particles, oriented in the same direction.
Chewy	Mechanical textural attribute related to cohesiveness and to the length of time or the number of chews required to masticate a solid product into a state ready for swallowing. Chewy: moderate level
Sticky	Mechanical textural attribute relating to the force required to remove material that adheres to the mouth or to a substrate. Sticky: low level
Pasty	Mechanical textural attribute related to the cohesiveness of a tender product. In the mouth, it is related to the effort required to disintegrate the product to the state ready for swallowing. Pasty: moderate level
Bitter	Organoleptic attribute of pure substances or mixtures which produces the bitter taste. (caffeine, quinine)
Salty	Describes the basic taste produced by aqueous solutions of various substances such as sodium chloride.
Grainy	Geometrical textural attribute relating to the perception of the size and shape of particles in a product. Grainy: moderate level

The formal assessment was performed in individual booths. Consumers took an average period of 8.52 min to complete the test. At the beginning of the tasting session, the consumers were asked to rate their current level of hunger on a one-to-nine scale, ranging from "Not hungry at all" to "Very hungry", to ensure consumers were not extremely hungry at the time of the test and this may affect their results. The products, labelled with 3-digit codes, were presented according to a sequential monadic order following a design to balance out order and carry-over effects in the global data set. For each product, consumers rated their liking and satiety expectations, answered a CATA (check-all-that-apply) question, filled in demographic characteristics (Gender: male, female, other (write), and age), and declared their consumption behaviour.

The questions were based on Nguyen et al. (2017) questionnaire. Consumers rated their liking (9-point scale; 1 = Dislike extremely; 9 = Like extremely) and the satiety expectation ("For how long do you think you would feel full from this bread?" rated on a 9-point scale; 1 = "hungry again at once" to 6 = "full for five hours or longer"), as well as their expected satiation("How full do you think you would get eating this bread?" rated on a 9-point scale; 1 = "Not full at all" to 9 = "Very full"). Consumers were then asked to "Choose all the attributes/terms that apply to this bread" on a CATA question a list of 28 hedonic and descriptive sensory attributes (good flavour, bad flavour, bitter taste, salt taste, acidic taste, sweet taste, grain/cereal flavour, roasted flavour, raw flavour, spicy flavour, yeast flavour, clawing flavour, taste of sourdough, compact, tough, fibrous, crumbly, dough-like, dry, heavy, juicy, soft, porous, sticky, chewy, coarse, hard, airy) and 16 usage and attitude terms (appealing, not appealing, healthy/nutritious, unhealthy, fibrous, satiating, light, suitable for lunch pack, "everyday" bread, weekend bread, suitable for breakfast, suitable for lunch, suitable for dinner, suitable for supper, "if the price was the same as the bread I usually buy, I would buy this bread", "I would not buy this bread, even if the price was the same as the bread I usually buy"). All the above attributes were randomised within and across consumers. Finally, consumers were asked on their consumption behaviour with question "To which meal do you usually eat bread?" (with options for "breakfast", "lunch", "dinner", "supper", "in-between meal"); and "How many slices of bread do you usually eat in a day (breakfast, sandwich, with other foods etc.)?" (with options from 1= "1 slice" to 6= "more than 5 slices").

2.6. Data collection and analysis

Data from the sensory test and consumer test were collected with EyeQuestion (Logic8 BV, The Netherlands). Data of the video recordings of the panel were first analysed on FaceReader and then imported to Observer XT (package for the collection, analysis, and presentation of observational data), so that they can be grouped based on the different samples for all assessors.

TDS data were collected with EyeQuestion and presented as TDS curves with standardised times (from T0 to T100). Through EyeQuestion were also obtained the chewing periods of the panel data, in contrary to the chewing motions that were counted manually by an experimenter. A Linear Mixed Model ANOVA with the sample as a fixed effect and the assessor as a random effect was applied to the oral processing behaviour data (intake, duration of chewing period, number of chew motions), followed by a pairwise comparison post-hoc test (Tukey post hoc test with significance level 0.05) to examine the differences between the samples.

Liking, satiety and satiation scores that differed between the breads were compared using two-way ANOVA with Tukey's post-hoc test. Cochran's Q test was carried out on the CATA results, followed by McNemar post-hoc test, to identify significant differences between samples for each attribute. All the analysis was done using Rstudio (Version R i384 4.0.3) and EyeQuestion's data analysis tool EyeOpenR.

3. Results

3.1. Sensory testing

3.1.1. Dynamic texture perceptions via TDS

The TDS curves of the three breads are presented in Fig. 1, in terms of the dominance rate of each attribute for the period of mastication process from the panel (Pineau et al., 2009). Data from each assessor were

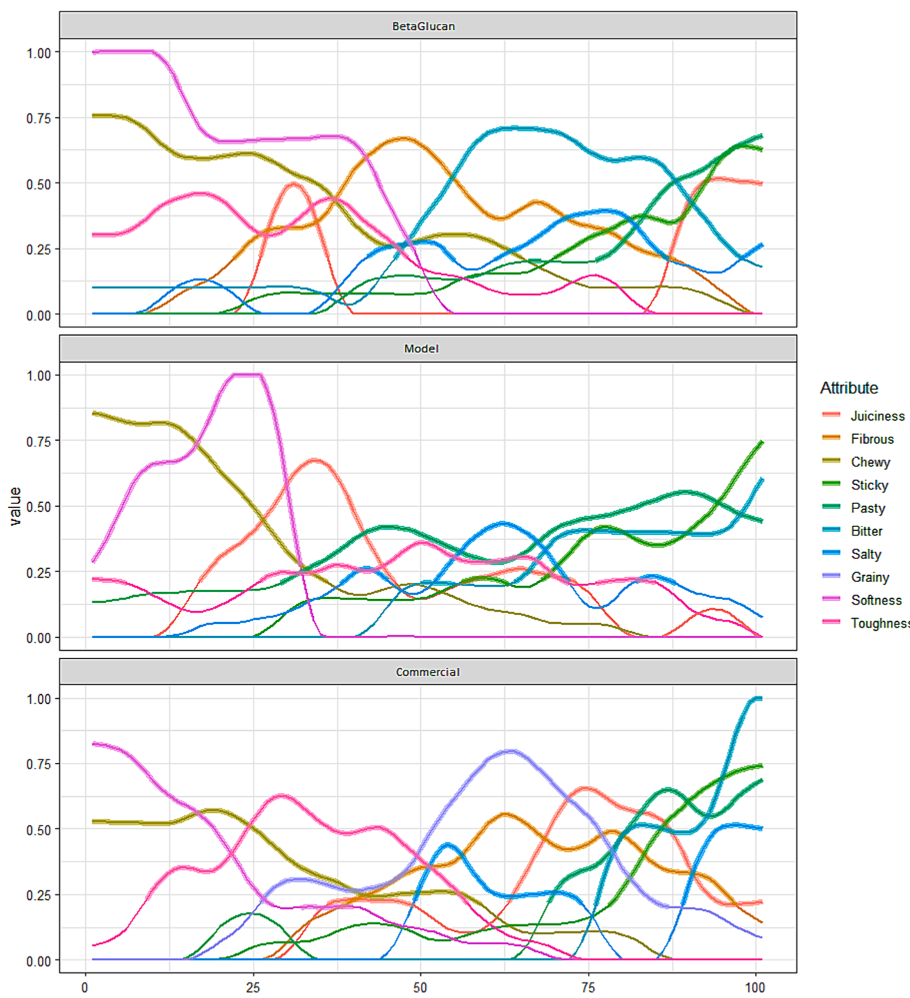

Fig. 1. The TDS curves of the three breads; the X-axis shows the standardised time (for T0 to T100, % of consumption time) and the Y-axis corresponds to the dominance rate of the chosen attributes at a specific time (%). Thick lines show that in that time period, the indicated attribute dominance is higher than the significance level.

normalised adapting to each individual's mastication duration and obtaining comparable time scales within individuals, from T = 0 to T = 100 (Nguyen et al., 2017).

TDS curves were different both in dominance rates and sequence of appearance of the attributes among the three breads, fulfilling the objective of the sample selection that aimed at having breads with different enough textural properties from a dynamic temporal perception. For the BetaGlucan and Commercial breads, the attributes of softness and chewy were perceived as highly dominant during the first part of the consumption (T0-T25), while the Model bread was not dominantly soft. Additionally, the BetaGlucan sample was dominant in toughness in the same period (defined as cohesiveness related to chewiness). For all three samples, sticky was one of the dominant attributes at the end of the oral processing (T75-T100). During the same mastication period, BetaGlucan also showed a high dominance in pasty and juiciness attributes, while Model was also considered high in pastiness and bitterness. Finally, the Commercial was perceived as dominantly pasty and bitter. In BetaGlucan bread, fibrous was dominant between T25 and T75, and salty attribute in the middle period. Toughness and grainy were dominant for the Commercial bread between T25 to T50 and T50 to T75 respectively. In contrast, the Model bread presented a decline in the dominance of attributes in the period between T25 to T75, suggesting a less complex sample.

3.1.2. *Face reading data*

The tested variables for ANOVA were the duration of chewing period (meaning the time since the intake until the bolus is ready to swallow) and the number of chew motions (meaning the number of bites after the intake, until the bolus is ready to swallow). The samples were statistically different for the oral processing behaviour data on the duration of chewing period ($p = 0.0001$) and number of chewing motions ($p = 0.03$).

When testing the duration of chewing period (Fig. 2 a), the post-hoc test shows that the Commercial and the BetaGlucan breads are significantly different with BetaGlucan bread needing a significantly longer chewing period. The Model sample was not significantly different to either of the other two breads. The same effect was observed for the number of chew motions in the mastication process, with the BetaGlucan bread having a significantly higher number of chew motions during mastication (Fig. 2 b), and no significant differences for the Model with the other samples.

3.2. *Consumer testing*

3.2.1. *Overall liking, expectations of satiation and satiety*

Table 2 presents the mean results for the overall population participating in the consumer test on liking and expected satiation and satiety. ANOVA showed significant differences in overall liking and expecting satiation and satiety between the three products. The Commercial bread was liked significantly more than the BetaGlucan, and the Model was the least liked. In terms of expected satiation, the Model bread was rated as the least satiating, followed by the Commercial with the BetaGlucan being the most satiating (significantly different to the Model sample). The BetaGlucan bread had the highest rating in expected satiation and satiety and was medium liked. It must be mentioned, however, that both BetaGlucan and Model are prototypes not optimised for commercial sale, made specifically to have a clinical effect, so the comparison in acceptability to a commercial product from the market is for characterization purposes only.

Table 2
Means and significant differences via Tukey test.

	BetaGlucan	Model	Commercial
Liking	5.0 B	4.2 C	5.7 A
Expected satiation	5.4 A	4.9 B	5.1 AB
Expected satiety	3.7 A	3.5 B	3.5 B

Products associated with different letters are significantly different at 5 %

3.2.2. *CATA question*

Out of 28 hedonic and descriptive sensory attributes listed in the CATA questionnaire, Cochran's Q test and McNemar post-hoc test (Table 3) indicated that 21 of them presented significant differences between the samples. No significant differences among the three breads were found in the frequencies of selection for acidic taste, sweet taste, roasted flavour, taste of sourdough, chewy, coarse, and hard (p-value higher than 0.05). The attributes sticky, dough-like, and compact were

Table 3
Cochran's Q test and McNemar post-hoc test for the significant hedonic and descriptive sensory attributes for the three breads.

	P-value	BetaGlucan	Model	Commercial
Good flavor	<0.001	43 A	18 B	55 A
Bad flavor	0,002	8 A	13 A	0 B
Bitter taste	0,005	4 AB	12 A	2 B
Salt taste	<0.001	27 A	24 A	6 B
Grain/cereal flavor	<0.001	16 B	26 B	44 A
Raw flavor	<0.001	29 A	7 B	3 B
Spicy flavor	0,004	9 A	13 A	1 B
Yeast flavor	0,006	16 AB	24 A	8 B
Cloying flavor	<0.001	7 B	22 A	3 B
Compact	<0.001	51 A	22 B	3 C
Tough	0,021	28 A	13 B	16 AB
Fibrous	0,01	6 B	19 A	11 AB
Crumbly	<0.001	13 B	29 A	5 B
Dough-like	<0.001	65 A	11 B	22 B
Dry	<0.001	11 B	72 A	18 B
Heavy	<0.001	24 A	17 A	1 B
Juicy	<0.001	55 A	12 B	59 A
Soft	<0.001	63 A	32 B	78 A
Porous	0,008	9 B	14 AB	24 A
Sticky	<0.001	52 A	12 C	30 B
Airy	<0.001	16 B	28 B	72 A

Products associated to different letter are significantly different at 5 %

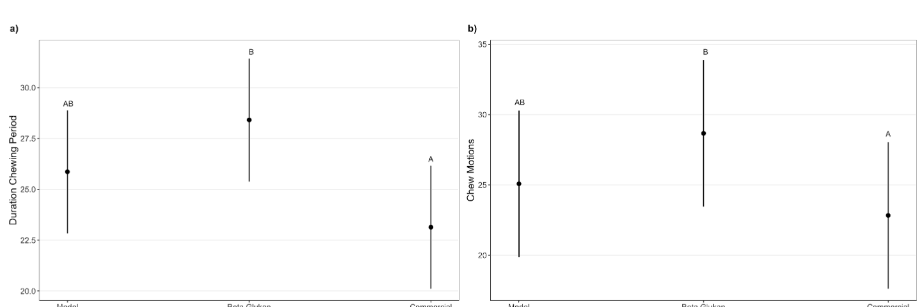

Fig. 2. Post-hoc pairwise comparison regarding duration of chewing period (a) and number of chew motions (b). Different letters (A,B) show significant differences.

selected more frequently in the BetaGlucan as expected, with all three breads being statistically different for these three attributes. The Model bread was described as the least associated with juicy and soft, as well as more frequently described as dry and cloying in flavour; also, significantly more associated with the attributes fibrous and crumbly as compared to the other two breads, while the Commercial was more associated to grainy and airy, as well as the least compact.

Regarding the 16 usage & attitude attributes (See Table 4), the 13 were found to have significant difference within the three breads. Healthy/nutritious, unhealthy, and fibrous attributes did not differ within the three breads as perceived by consumers. In the CATA question, the BetaGlucan was the most frequently described as satiating, however the Commercial was considered as the lightest and most suitable for all suggested meals, with significant differences with the Model, while for some of the meals, the BetaGlucan bread was not significantly different in suitability in many of the instances (weekend, dinner, breakfast, lunch). The BetaGlucan and the Commercial breads were significantly more described as appealing; on the contrary, the least appealing out of the three was the Model.

4. Discussion

4.1. General discussion

Mastication duration and number of chewing motions, as automatically measured with face reading were significantly different among the breads in this study. This adds to the body of research, which suggests that food properties can influence the chewing period and amount of chews leading to the formation of a swallowable bolus (Lenfant et al., 2009) and with the novelty face reading can be successfully used for following those changes automatically, and potentially from an implicit perspective (if the subject is not aware of the fact that the behaviour is measured).

Furthermore, the temporal sequence of the different textural attributes in the studied breads can be compared to previous literature findings. For example, Lenfant et al. (2009) found that for the wheat flakes they used, there was a specific pattern for most of them regarding the temporal sensation. In the beginning of the chewing period, the most dominant sensations were hardness, crackliness and crispness; in the middle of eating period the attribute brittleness was dominating, and at the end of the mastication, the stickiness was mostly perceived. All these temporal aspects can, in turn, be related to expectations of satiety and satiation by consumers (Lenfant et al., 2009). Accordingly and after observation in Fig. 3 of the current research' findings, BetaGlucan bread was described as more dominantly fibrous in the beginning, as well as less dominantly juicy throughout the mastication; similar sensations were highlighted as drivers of satiety in previous research on barley bread, like fibre-related coarseness and not being dominantly juicy (Nguyen et al., 2017). This also aligns with the assessment of consumers in our study, where BetaGlucan was perceived as the most satiating bread. However, it is worth noticing that all three products had a higher toughness dominance rate at the beginning of the oral processing compared to later stages until the middle of mastication; and almost until the end of the mastication process for the Model bread, possibly because of its higher dryness and the difficulty to moisten the particles. Stickiness was the dominant sensation for all products at the end of the oral processing, possibly perceived as signalling for a safe bolus swallow, as indicated in previous studies (Lenfant et al., 2009).

Table 4
Cochran's Q test and McNemar post-hoc test for each usage & attitude attribute for the three breads.

	P-value	BetaGlucan	Model	Commercial
Appealing	0,001	15 A	4 B	22 A
Not appealing	<0.001	28 A	41 A	12 B
Satiating	<0.001	39 A	18 B	16 B
Light	<0.001	16 B	18 B	44 A
Suitable for lunch pack	0,001	51 B	56 B	77 A
"Everyday" bread	<0.001	49 B	60 B	84 A
Weekend bread	0,008	8 AB	4 B	16 A
Suitable for dinner	0,026	38 AB	27 B	46 A
Suitable for breakfast	0,05	50 AB	48 B	64 A
Suitable for lunch	0,01	50 AB	43 B	64 A
Suitable for supper	<0.001	29 B	22 B	54 A
I would buy this bread	<0.001	29 A	15 B	41 A
I would not buy this bread	<0.001	61 A	64 A	31 B

Products associated to different letter are significantly different at 5 %

Consumers in the present study rated the BetaGlucan bread as the highest in expected satiation, which was also reflected in CATA question as the consumers associated it more frequently with the term "satiating". This is in line with the data obtained from face reading, with significantly higher number of chewing motions and higher duration of chewing period. Consumers further described the BetaGlucan sample with higher rates in selection of the attributes compact, tough, dough-like, and sticky; some of those textural attributes identified in previous studies as a major drivers of food's eating rate and consuming behaviour, where foods with higher elasticity and hardness require a higher number of chews and consequently decreasing the food and energy intake (Bolhuis & Forde, 2020). More concretely, these results are also in line with results reported by (Nguyen et al., 2017) on breads with different textures, in which dynamic textural changes responsible for driving satiety and satiation expectations, in particular chewiness and coarseness dominance as drivers of enhanced satiety, whereas dryness and crumbliness were linked to less satiating breads.

The Model bread was the least appealing for consumers and the least chosen in the CATA question for any type of meal throughout the day, which may partially be due to the higher rating in cloying flavour by consumers, as compared to the other two breads, as well as the rancid flavour mentioned by the trained panel. "Rancid" attribute that was detected in the pre-testing but was not included in the final list of attributes. However, it is encouraging that when comparing between Model and BetaGlucan samples then the objectives of their product design were attained, with BetaGlucan having significantly higher expected satiety and satiation as rated by consumers and being also significantly better liked than the comparable control Model.

4.2. Methodological considerations

FaceReader allows for automatic and potentially implicit measurement of oral processing behaviour (if the subject is not aware of the fact that the behaviour is measured and that it measures unconscious, automatic processes), and allows for automatic extraction of the oral processing behaviour parameters. Even if the current work could successfully use face reading to assess oral processing behaviour and relate it to product characteristics and satiety expectations, there is a large margin for optimization on FaceReader's 'food consumption behaviour' module used for this application, which is still considered as "experimental" (beta version) by the manufacturers. It is safe to say that the software can be used to study oral processing behaviour, and more precisely the number of chewing motions and the chewing period, in a trained panel testing, as highlighted by the present study. The assessors are trained to follow specific and detailed instructions, but even in that case much pre-testing and re-adjusting was needed for each individual assessor, to being able to have good results in the measurements of intake, chewing motions and chewing period.

FaceReader software was able to automatically analyse the oral processing incidences, like the chewing period and number of chew motions. However, in a manual counting of the number of chewing motions of every assessor, it was found that there was an underestimated measurement from FaceReader (mean of 7.1 number of chewing motions); and also an underestimation of the duration of chewing period from FaceReader (mean of 4.1 s) compared to the EyeQuestion's

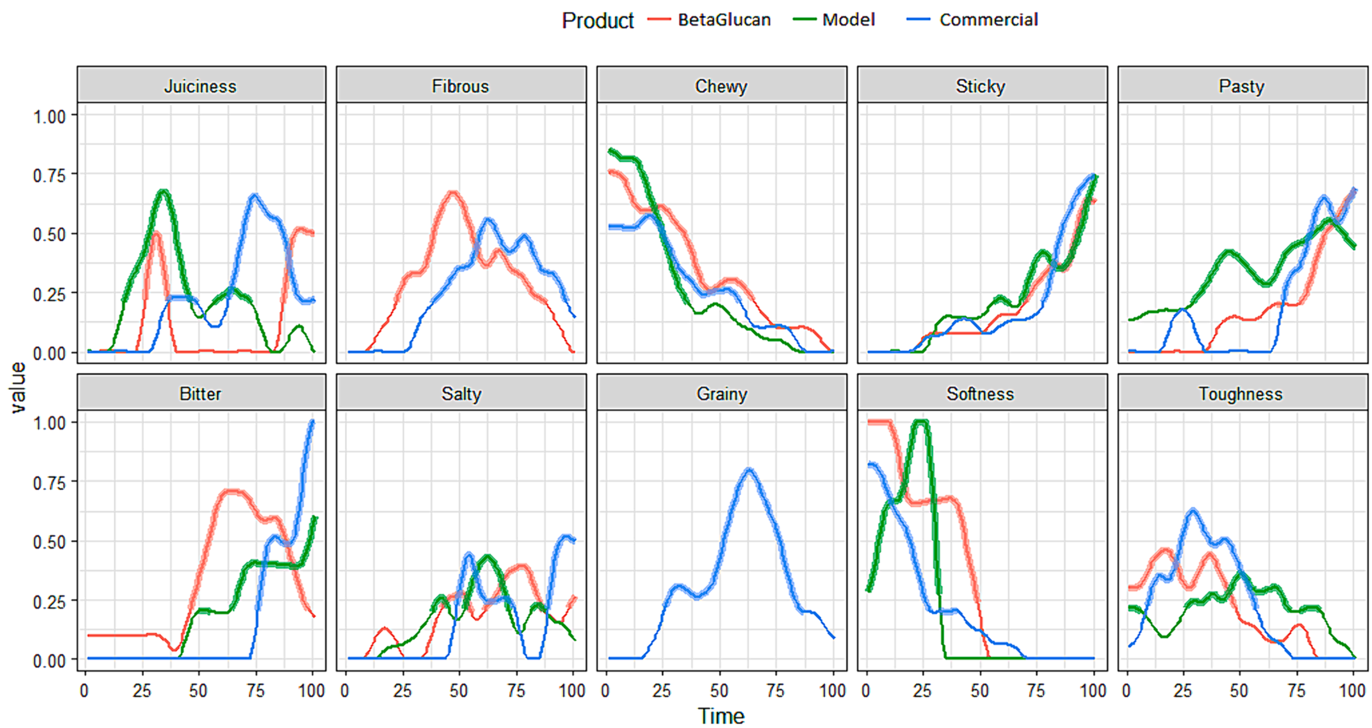

Fig. 3. Dominance of each attribute individually in TDS for the three breads (thick lines show that in that time period, the indicated attribute dominance is higher than the significance level).

automated data (Table 5). A further issue was that regardless of the automated calculation, other parts in the procedure required a lot of manual work. For example, each file had to be imported on the software manually to ensure that the order was right for each assessor, sample, and repetition. Moreover, each file of the imported videos had to be renamed when in the software to warrant the correct optimisation and then transfer to Observer X for combining the data of different assessors. All this procedure poses a risk of human error and is time consuming, enabling a risk of software to fail when importing a big amount of video recordings.

Added to this, we found that the use of face reading to assess eating behaviour was not that reliable in a consumer test. Even if collected, these data were not presented in the current study because of the several issues. Nevertheless, some remarks are given below by observation of the video recordings and some preliminary data extracted from FaceReader. To avoid the re-adjusting of the cameras for each individual, cameras with a wider angle were used and turned on the side, with the intention of covering all different heights of consumers; adjusting the camera, and checking one by one the software when collecting the data would have taken too long time for such a large number of consumers (136), and not be practical in a consumer test. Results were collected with this set up. However, FaceReader did not record the oral processing behaviour in many of the cases. More details about the position and type of the camera should be provided by the manufacturer, as well as adjusted sensitivity for the intake recording would be desired. Further research, though, is needed in this direction.

Moreover, these automatic measures through face reading are quite challenging in many ways when applied with consumers. Even if the consumers had clear instructions on their screen about the procedure of the test, many of them did not follow them: not waiting for the countdown, forgetting to pick up the sample and after the countdown looking for it, biting half of the sample instead of consuming it all in one intake, covering the mouth with their hand during mastication or the intake, looking in many different directions while chewing, and clicking to continue to the next step right after the intake are some of the observed cases that occurred. In all the above examples, incidences of intake and/or chewing motions were not recorded from the software. Also, FaceReader appears to be very sensitive to hand movements visible in the camera, especially when close to the face. In those cases, it will most likely interpret it as an intake, or as an extra chewing motion. The software should detect intake when the consumer puts the sample in mouth, however, some consumers moved their arm and an intake was mistakenly recorded, or sometimes not registered at all. Many technical aspects of the measurements of oral processing behaviour by face reading are needed.

Another methodological consideration is the fact that oral processing parameters were measured in video recording during the TDS assessment, this may mean that participants display a different mastication behaviour and times might have been longer than in normal consumption; however, we expect this will have a similar effect among samples and has not influenced differences.

5. Conclusions

This paper adds to the literature describing how textural properties influence food dynamic sensory perception during consumption, and in turn affecting oral processing behaviour and satiety related expectations. Results of the dynamic textural properties of the tested breads were in line with consumers' expectations of satiation and satiety. BetaGlucan bread, formulated to be more satiating, was indeed rated as highest in expected satiation, and more frequently associated in the CATA question to "satiating" term, and described as tough, sticky, compact and dough-like attributes; meanwhile, it had the highest number of chewing motions and longest chewing period.

The novelty of the present study is to show a simple, automatic procedure for the measurement of oral processing behaviour through face reading. The parameters automatically extracted by the software were in line with self-reported, explicit measures of satiety expectations as determined by the texture changes in the products. However, there is still a lot of potential for optimization of the function of automatic consumption behaviour measurements of Face Reader software, together with a better adjustment of the protocols to use in consumer

Table 5
Number of chewing motions and duration of chewing period of the panel extracted from FaceReader (automatic measurement) compared to counted number of chewing motions from a researcher by observing the videos (manual measurement) and the duration of chewing period measured during TDS (EyeQuestion).

Assessor	Product	Replicate	Duration of chewing periods by FR	Duration of chewing period measured during TDS (Eye Question)	Duration of chewing period Over or Under registration by FR (in seconds)	Number of chew motions by FR	Number of chew motions (counted by looking at videos)	Number of chew motions Over or Under registration by FR
1	BetaGlucan	1	24.8	27.2	2.4	29	25	−4
1	BetaGlucan	2	23.1	25.7	2.6	23	25	2
1	BetaGlucan	3	23.4	25.7	2.3	26	25	−1
2	BetaGlucan	1	26.8	29.0	2.2	26	28	2
2	BetaGlucan	2	24.1	26.8	2.7	26	28	2
2	BetaGlucan	3	32.4	34.6	2.2	41	36	−5
3	BetaGlucan	1	28.0	30.3	2.3	35	45	10
3	BetaGlucan	2	24.8	27.7	2.9	32	42	10
3	BetaGlucan	3	31.2	33.9	2.7	36	45	9
4	BetaGlucan	1	28.3	34.1	5.8	28	51	23
4	BetaGlucan	2	34.2	40.7	6.5	38	49	11
4	BetaGlucan	3	29.6	36.3	6.7	21	48	27
5	BetaGlucan	1	35.7	39.1	3.4	45	48	3
5	BetaGlucan	2	27.0	31.6	4.6	35	35	0
5	BetaGlucan	3	36.6	40.0	3.4	43	45	2
6	BetaGlucan	1	23.7	26.9	3.2	23	34	11
6	BetaGlucan	2	23.5	26.0	2.5	31	35	4
6	BetaGlucan	3	26.9	31.0	4.1	26	34	8
7	BetaGlucan	1	29.8	33.0	3.2	17	33	16
7	BetaGlucan	2	20.2	35.1	14.9	15	34	19
7	BetaGlucan	3	37.2	40.1	2.9	23	37	14
8	BetaGlucan	1	17.7	26.8	9.1	22	22	0
8	BetaGlucan	2	27.6	33.3	5.7	30	32	2
8	BetaGlucan	3	22.3	34.4	12.1	17	37	20
1	Model	1	25.9	27.7	1.8	26	24	−2
1	Model	2	22.6	26.2	3.6	21	22	1
1	Model	3	23.1	23.0	−0.1	24	22	−2
2	Model	1	13.9	20.3	6.4	13	15	2
2	Model	2	24.6	22.1	−2.5	26	27	1
2	Model	3	18.0	19.3	1.3	18	20	2
3	Model	1	25.0	23.5	−1.5	26	41	15
3	Model	2	23.7	23.7	0.0	35	36	1
3	Model	3	30.1	29.0	−1.1	42	45	3
4	Model	1	26.6	29.7	3.1	12	40	28
4	Model	2	26.9	32.3	5.4	17	39	22
4	Model	3	17.2	32.8	15.6	11	24	13
5	Model	1	38.6	30.8	−7.8	45	52	7
5	Model	2	34.7	28.1	−6.6	47	47	0
5	Model	3	25.8	31.3	5.5	31	39	8
6	Model	1	21.1	24.6	3.5	22	28	6
6	Model	2	24.4	19.5	−4.9	28	30	2
6	Model	3	26.4	24.9	−1.5	31	36	5
7	Model	1	30.8	32.6	1.8	15	30	15
7	Model	2	29.1	27.5	−1.6	24	30	6
7	Model	3	30.8	29.8	−1.0	25	33	8
8	Model	1	19.0	21.8	2.8	24	21	−3
8	Model	2	16.3	21.6	5.3	16	27	11
8	Model	3	22.1	21.1	−1.0	23	24	1
1	Commercial	1	25.3	28.3	3.0	29	25	−4
1	Commercial	2	20.5	24.5	4.0	18	24	6
1	Commercial	3	22.0	25.2	3.2	18	23	5
2	Commercial	1	18.1	16.9	−1.2	23	22	−1
2	Commercial	2	19.4	27.9	8.5	20	24	4
2	Commercial	3	7.2	18.3	11.1	2	23	21
3	Commercial	1	22.3	27.5	5.2	28	36	8
3	Commercial	2	21.5	25.6	4.1	28	34	6
3	Commercial	3	27.0	32.2	5.2	38	37	−1
4	Commercial	1	22.9	34.1	11.2	25	36	11
4	Commercial	2	25.6	35.0	9.4	18	41	23
4	Commercial	3	24.8	37.9	13.1	17	41	24
5	Commercial	1	27.6	41.7	14.1	34	38	4
5	Commercial	2	24.7	38.4	13.7	29	35	6
5	Commercial	3	28.1	29.4	1.3	35	42	7
6	Commercial	1	21.5	23.6	2.1	23	31	8
6	Commercial	2	17.1	26.6	9.5	21	26	5
6	Commercial	3	21.3	29.2	7.9	21	31	10
7	Commercial	1	30.2	33.2	3.0	30	31	1
7	Commercial	2	24.9	29.5	4.6	10	28	18
7	Commercial	3	26.6	32.6	6.0	20	31	11
8	Commercial	1	20.2	22.7	2.5	22	23	1
8	Commercial	2	16.7	23.6	6.9	17	22	5
8	Commercial	3	18.0	27.5	9.5	22	20	−2

testing, that we hereby discussed.

Future work should focus on further optimising protocols on face reading and the application of those to study changes in consumers' eating behaviour in other types of foods and food categories, for being able to extend the results of this study.

Ethical statement

The authors declare that the research in this paper comply with ethical principles and Applicable international, EU and national law (in particular, EU Directive 95/46/EC).

Experiments conducted on humans are set up in agreement with Norwegian ethical requirements on research activities and personal data protection. Thus, protocols are sent for approval to the Norwegian Agency for Shared Services in Education and Research (Sikt, Kunnskapssektorens tjenesteleverandør, https://sikt.no/en/about-sikt), which is responsible for granting licenses on behalf of the Data Inspectorate in relation to the Personal Data Act and Health Register Act.

All participants signed an informed consent and were free to withdraw from the studies at any time without providing a reason for withdrawal and without penalty. No sensitive data was collected (for example, on religion, sexual orientation, race, ethnicity, etc.). Data was used only for scientific purposes only (no commercial purposes). Security Strategies for personal data, confidentiality and protection were adopted through codification system procedures. Storage and handling of such data guaranteed the anonymity of the participants: in all result files, there was no nominative data. This means recruitment data (with personal data) and results data are at all times separated and never stored together.

CRediT authorship contribution statement

Aikaterini Katsikari: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Mads Erling Pedersen:** Writing – review & editing, Supervision, Methodology, Data curation. **Ingunn Berget:** Writing – review & editing, Data curation. **Paula Varela:** Writing – review & editing, Supervision, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgements

The authors wish to thank Anne Rieder and Simon Balance to provide the breads from Carbhealth project for our experiments. We also thank the Stiftelsen for Landbrukets Næringsmiddelforskning (SNLF) for the PhD scholarship awarded to author Katerina Katsikari and to the Research Council of Norway and the Norwegian Fund for Research Fees for Agricultural Products (FFL) for funding, through the project "FoodForFuture" (Project number 314318; 2021-2024).

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