Norwegian University of Life Sciences
Faculty of Veterinary Medicine and Biosciences
Department of Chemistry, Biotechnology and
Food Science

Master Thesis 2015
60 credits

Oral processing and satiety perception of bread

Understanding the role of texture and oral processing in consumers' perception of satiety

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Abstract

The worldwide prevalence of obesity doubled between 1980 and 2014. This rise lends great interests to preventive measurement aimed at satiety enhancement, as healthy products of enhanced satiety potentially could encourage responsible consumption. The objective of this Master thesis was to understand the role of texture and oral processing of bread in consumers' perception of satiety. Eight iso-caloric breads were manufactured, using the same procedure and ingredients but manipulating texture by changing process parameters. A trained sensory panel evaluated the eight samples focusing on dynamic perception of texture, using the sensory method Temporal Dominance of Sensations (TDS). Based on the results, four samples with well-differentiated dynamic texture profiles were selected. The sensory panel analyzed the four chosen samples using Quantitative Descriptive Analysis (QDA) in order to obtain a complete sensory description of the breads. A consumer test was performed where consumers evaluated their overall liking, expected satiation and expected satiety for the four samples. They answered to a check-all-that-apply (CATA) question as well, for both real samples and for their ideal bread, to provide sensory and usage profiles for the products.

The results showed that texture during oral processing was not static and attributes evolved during mastication, where different attributes were dominant at different stages. Texture attributes related to a more demanding processing before the bolus was ready to swallow, seemed to describe the breads expected to be the most satiating. These texture attributes caused changes in oral processing time, which has been shown to influence satiety; however, this does not seem to be the only factor influencing expected satiety. Many factors might influence the food intake during an eating event, and from this study, it is clear that texture during oral processing is a contributing factor, and that the sequence and dominance of texture attributes perceived during oral processing are of importance in satiety perception.

Sammendrag

Den verdensomspennende utbredelsen av fedme ble fordoblet fra 1980 til 2014. Økningen i forekomst av fedme gir interesse for forebyggende tiltak rettet mot matvarer som gir økt metthetsfølelse. Sunne produkter som gir økt metthet kan potensielt redusere overflødig energiinntak, og dermed bidra til å snu den negative utviklingen. Målet med denne masteroppgaven var å forstå hvilken rolle tekstur og oral prosessering spiller i forbrukernes metthetsoppfatning. Åtte brød ble produsert med samme oppskrift og fremgangsmåte, men tekstur ble manipulert ved å endre prosessparameterne. Et trent sensorisk panel evaluerte de åtte brødene med fokus på tekstur, ved hjelp av den sensoriske metoden Temporal Dominance of Sensations (TDS). Basert på resultatene ble fire prøver med differensierte dynamiske teksturprofiler valgt ut. Det sensoriske panelet analyserte disse utvalgte prøvene ved hjelp av beskrivende analyse (Quantitative Descriptive Analysis), for å få en komplett sensorisk beskrivelse av brødene. En forbrukertest ble utført hvor de som deltok evaluerte hvor godt de likte brødene og forventet metthetsfølelse. For å få sensoriske- og bruksprofiler for brødene svarte forbrukerne på Check-all-that-apply (CATA) spørsmål, både for de fire prøvene og for det de så for seg som sitt ideelle brød.

Resultatene viste at teksturegenskapene utvikler seg under tygging, og at forskjellige egenskaper var dominerende på forskjellige stadier av oral prosessering. Teksturegenskaper relatert til en mer krevende prosessering før brødet var klart til å svelges, så ut til å beskrive de mest mettende brødene. Disse teksturegenskapene endret oral prosesseringstid, noe som har vist seg å påvirke metthetsfølelse i tidligere studier, men dette ser ikke ut til å være den eneste faktoren som har påvirket forventet metthetsfølelse. Mange faktorer kan påvirke størrelsen på et måltid, og fra denne studien er det klart at teksturen i brød under oral prosessering er en medvirkende faktor. Rekkefølgen og dominansen av teksturegenskapene oppfattet mens man spiser er også av betydning for metthetsoppfatningen.

Acknowledgements

I would like to offer my sincere thanks to my Nofima supervisors: Dr. Valérie Lengard Almli and Dr. Paula Varela Tomasco, for all the knowledge and guidance given to me. The past 10 months have been interesting and educational.

I wish to thank all staff members at the department of Consumer and Sensory Sciences for all their help, kindness and shared knowledge, my stay at Nofima has really been enriching.

A particular thanks to:

- Anne Marit Holten, Ida Mailen Kasbo, Kristine Svartebekk Myhrer and Mats Carlehög for their assistance with the sensory analyses and consumer test, and of course, for all the moral support.
- André Løvaas for his help with sample manufacturing, I could not have managed without his expertise.
- Dr. Stefan Sahlstrøm for sharing his knowledge on cereals.
- The trained sensory panelists at Nofima and the consumers for their participation in this study.
- My fellow Master students at Nofima for their solidarity and friendship.

Ås 13.05.2015

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1. Preface

This Master project was part of a 2-year Master degree in Food science at the Norwegian University of Life Sciences, Department of Chemistry, Biotechnology and Food Science, Ås, Norway.

The study was conducted during a 10-month internship at Nofima AS in Ås, Norway, at the department of Consumer and Sensory Sciences. It is a part of the project *Sensory strategies and consumer insight for healthy and palatable food* (conducted from 2012-2016), and is funded by the Fund for Research Levy on Agricultural Products. The objective of the project *Sensory strategies and consumer insight for healthy and palatable food* is to establish research-based knowledge on how sensory strategies and consumer insights may contribute to a healthy and palatable diet for the population. It has two strategies in investigation: Adaption of healthy food to the consumers' palates, and adaption of the consumer to appreciate healthy foods, based on learning and information.

This Master project was conducted in accordance with Nofima's strategies, to establish knowledge that might contribute when manufacturing products of higher satiating capacity, to potentially encourage lower food consumption as a preventive measure against overweight and obesity

2. Introduction

According to the World Health Organization (WHO) more than 1.9 billion adults were overweight (BMI>25) in 2014, of these over 600 million were obese (BMI>30). Common health consequences of overweight and obesity are cardiovascular diseases, diabetes, musculoskeletal disorders and cancer. The worldwide prevalence of obesity more than doubled between 1980 and 2014. This rise lends great interest to preventive measures aimed at satiety enhancement. Healthy products of enhanced satiety could allow better control of eating behavior and potentially encourage responsible consumption.

Simply thinking of food might affect appetite behaviors and can lead to physiological responses, and food's sensory input is able to serve as appetite stimulus (Berthoud 2007). Satiety expectations might be closely related to the structural changes that take place in the mouth, and sensory properties, especially texture, affect the assessment of the satiating capacity (Morell et al.). Sensory-specific satiety might have an important influence on the amount of food eaten (Sorensen et al. 2003).

The objective of this Master thesis was to understand the role of texture and oral processing of bread in consumers' perception of satiety.

Eight iso-caloric breads were manufactured, using the same procedure but manipulating texture by changing process parameters. A trained sensory panel evaluated the eight samples, focusing on texture, using the sensory method Temporal Dominance of Sensations (TDS). Based on the results, four samples with well-differentiated dynamic texture profiles were selected. The sensory panel analyzed the four chosen samples using Quantitative Descriptive Analysis (QDA) in order to obtain a complete sensory description of the breads. A consumer test was performed where consumers evaluated their overall liking, expected satiation and expected satiety for the four samples. They answered to a check-all-that-apply (CATA) question as well, for both real samples and for their ideal bread, to provide sensory and usage product profiles.

The thesis relates texture profiles to expected satiation and expected satiety, and discusses the results in light of complementary measures.

3. Theory- Oral processing and satiety

Different sensory attributes, including texture attributes probably reflect food properties at various stages of the oral processing. The role of oral movements in food perception may even extend to post-ingestive sensations of satiety or fullness (Chen & Engelen 2012).

3.1 Oral processing and texture

Oral processing is the process by which food enters the mouth, is transported, manipulated, broken down and swallowed. Food structure of solids is continuously evolving during oral processing (Chen & Engelen 2012). Texture is a sensory property and texture-testing instruments can detect and quantify certain physical parameters, however, only a human being can perceive and describe it. Texture is also a multi-parameter attribute and derives from the structure of the food (Szczesniak 2002). All foods have texture of some sort, ranging from tough to grainy and creamy, and texture is key to the appreciation and recognition of food. Texture is sensed by the hands, eyes, nose and ears, even before the food enters the mouth. When the food has entered the mouth, intraoral attributes can be sensed either while the bulk of the bolus is still in the mouth, or after the bulk of food has been swallowed (Chen & Engelen 2012).

Based on the structural state, foods can be categorized into three main groups, liquids, semi-solids and solids. The oral residence time is typically very short for liquids, longer for semi-solids and longest for solids. Solid foods have to be processed into bolus that can safely pass through the pharynx and esophagus to the stomach. Due to a longer oral residence time for solids, the consumer has more time to sense the different textural aspects of the food product. The degree to which the product has to be broken down depends on the hardness and water or fluid content. Consequently, hard, tough and dry foods stay longer in the mouth than soft or wet foods before swallowing. The main factors determining the readiness of food to be swallowed are fragmentation of the solid foods and their lubrication and aggregation to a food bolus as a function of time (Chen & Engelen 2012).

In a study on cereals by Lenfant et al. (2009) which aim was to describe the succession of perceptual events that happened in mouth during mastication, they found that mastication duration was significantly different among subjects, and they stated that individuals are known to have different chewing behaviors and that this partly explains why they perceive food texture differently. Individuals with shorter chewing cycles tended to concentrate more on the initial properties of food than individuals with longer chewing periods. Most of the texture changes occurred in the first half of the mastication. At the end, all boli was mostly perceived as sticky. They summarized the succession of oral manipulation as: 1) food positioning with the tongue in between the teeth, during this stage surface properties of the food are sensed by the tongue's mechanoreceptors; 2) the food is then chewed and fractured with the teeth, that is when hardness, crackiness and crispness might be perceived; 3) the food is comminuted into smaller pieces that may induce brittleness; 4) the food is moistened with saliva which helps to form a soft and cohesive bolus that may lead to increased stickiness.

3.2 Satiety and satiation

There are two different processes related to food intake. Satiation is defined as the process that leads to the termination of eating, and controls meal size. It is directly related to the feeling of fullness. Satiety refers to the processes that inhibit hunger between eating events (Brunstrom 2011).

3.2.1 Drivers of eating

It has been demonstrated that simply thinking of food can modulate neural activity in specific brain areas known to be involved in the cognitive control of appetite behaviors and can lead to physiological responses such as saliva, gastric acid, and insulin secretion. Sensory input, including visual, auditory and tactile sensation is able to serve as stimuli. When food is encountered, smell and taste act as stimuli to recall memorial representation of experiences with particular food items (Berthoud 2007). A range of hormones regulates appetite; some of them are called gut-brain peptides because they act as chemical signals from the gut to the brain. Some of the hormones can be classified as short-term regulators, such as Ghrelin, Peptide YY and Cholecystokinin (CCK). When the stomach is empty Ghrelin is secreted, which produces a sensation of hunger. Peptide YY is secreted in the ileum and colon, and signals satiation to terminate eating. This hormone will stay elevated after a meal, and prevents the stomach from emptying too quickly, thereby prolonging the feeling of satiety. CCK stimulates the brain and the sensory fibers of the vagus nerves, which has an appetitesuppressing effect. Gastric peristalsis also stimulates hunger: when the stomach is empty, hunger contractions will start, increasing in intensity over a period of hours (Saladin 2010).

In a research review Mela (2006) stated that there was a growing consensus that overeating in obesity reflects responsiveness to non-homeostatic stimuli, rather than a primary defect or failure of endogenous homeostatic systems involved in energy balance. Variation in obesity was not clearly related to variation in the hedonic experience or explicit pleasure of eating. Figure 1 shows a simplified overview of the influences of liking, internal state and external stimuli in everyday eating situations. Proximate drivers of desire to eat are the physiological and psychological state, liking and external stimuli based on environmental cues and triggers. Underlying processes are for example social context, reward and previous food experiences.

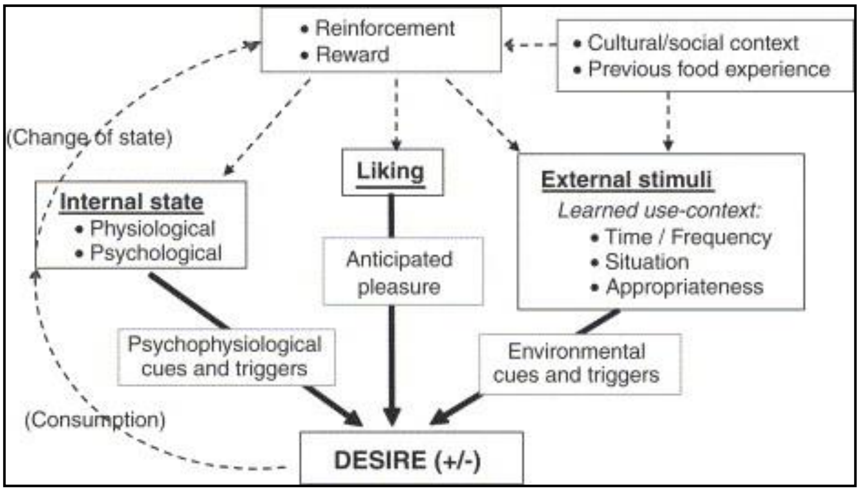


Figure 1. *Overview of different influences on satiety. Solid lines represent proximate drivers and dashed lines represent underlying processes (Mela 2006).*

3.2.2 Meal termination

Satiation determines the size of an eating occasion, and *fullness* and *boredom with taste* are two major reasons to stop eating. This might differ depending on type of meal, for example if you eat a single food boredom might occur earlier than with composite meals, where fullness might be more important for ending the meal. Termination of meals often arise through environmental factors, such as portion size (Blundell et al. 2010). The satiety cascade in

Figure 2 shows that cognitive factors, linked to meal quality, may play an important role in meal termination, based on prior experiences and associations.

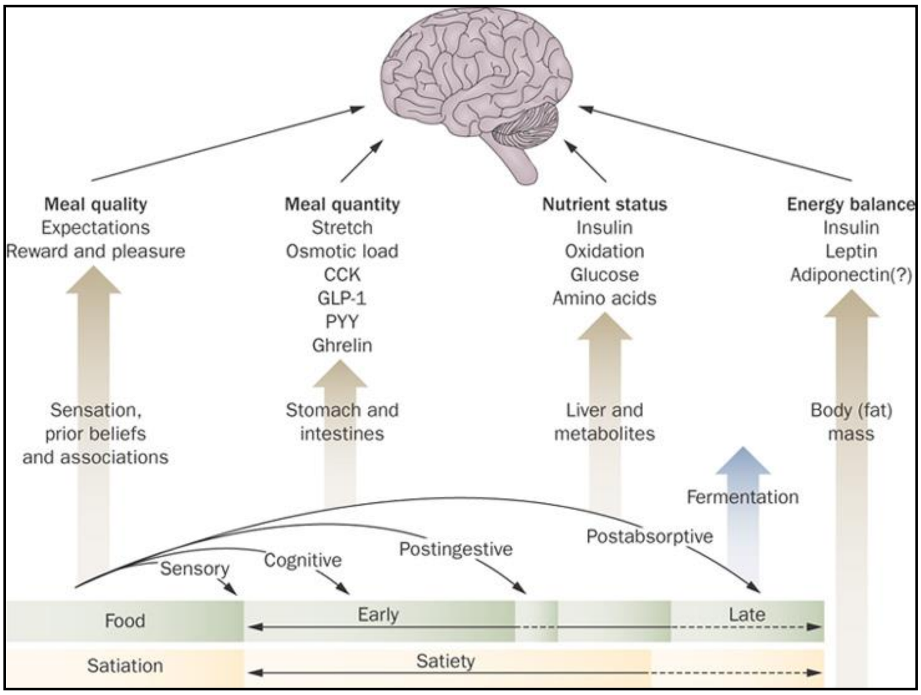


Figure 2. Satiety cascade. Before you eat and during early food intake satiation is more related to sensory and cognitive factors, and by the end of food intake and after food intake, post ingestive and post absorptive factors play a bigger role for satiety (Blundell 2010).

Sensory factors are more involved in what we eat, and metabolic factors may be more involved in how much we eat. Blundell et al. (2010) listed the metabolic and sensory aspects on satiation and satiety in three major groups:

1. **Metabolic satiation and satiety:** refers to all neural and hormonal signals transported from the gastrointestinal tract to the brain. These signals refer to stomach fullness and sensed by stretch receptors, but also to hormones involved in hunger and satiety, such as Ghrelin, Cholecystokinin (CCK), GLP-1 and PYY.

2. **Sensory specific satiation:** refers to the decline in reward value during consumption of food, i.e. because of repeated exposure to a particular sensory signal. This is boredom with the taste of a particular product.

3. **Sensory mediated satiation and satiety signals:** relates to learned satiety/cephalic phase response issues; when tasting a food people know immediately something about their satiety value. This is a conditioned response based on prior experience with the food.

3.3 The relation between oral processing and satiety

Satiety expectations can be closely related to the structural changes that take place in the mouth. Sensory properties affect the assessment of the satiating capacity, especially texture, which is directly related to orosensory exposure (Morell et al.). Texture effects are often more obvious with satiation than with satiety, however that does not mean that texture do not have an impact on satiety. Food with fibers can me more viscous and therefore lead to higher satiety (de Graaf 2012). Sorensen et al. (2003) described in a review that texture, smell, taste and appearance-specific satieties had been identified, and that sensory-specific satiety might have an important influence on the amount of food eaten. Hogenkamp and Schiöth (2013) summarized the results of 33 experiments, to get an impression of the effect of changes in bite size, number of chews, texture and eating rate on satiation and satiety. The results indicated that increasing the number of chews, reducing bite size and reducing eating rate reduces ad libitum food intake and improves satiety responses. However, both properties of a food (e.g. viscosity) and individual traits (e.g. bite size, chewing time) might lead to changes in eating behavior. Texture modification have been found to cause a reduction in the amount of food eaten, however, it might cause a decrease in palatability (Pritchard et al. 2014).

There has also been studies on the effect of oral processing on gut hormones. Kokkinos et al. (2010) studied the effect eating slowly has on postprandial response of gut hormones. They found that PYY and GLP-1 were higher after a 30 min meal than after a 5-min meal, and concluded that eating at a physiologically moderate pace leads to more pronounced anorexigenic gut peptide response than eating very fast, i.e. leads to increased satiation.

4. Theory- Methods

Sensory evaluation is a scientific method used to evoke, measure, analyze and interpret the response to products, through sight, smell, touch, taste and hearing. Sensory evaluation is a quantitative science in which numerical data are collected to establish the relations between human responses and product characteristics (Lawless & Heymann 2010).

4.1 Sensory testing

Descriptive procedures have traditionally been static, where average intensities of evaluated attributes are described, one example of a common technique is Quantitative Descriptive Analysis (QDA). However, in recent years dynamic methods have emerged allowing the study of the changes in perception during mastication as a function of time, one example of a dynamic method is Temporal Dominance of Sensations (TDS).

4.1.1 Quantitative descriptive analysis (QDA)

Quantitative descriptive analysis gives a complete sensory description of products. Usually the analysis is performed by between 8-12 trained panelists who rate attributes on an intensity scale, which allows the data to be statistically analyzed by ANalysis Of VAriance (ANOVA). Descriptive analysis is generally useful in any situation where a detailed specification of a single product or differences between several products are desired (Lawless & Heymann 2010). During training, the judges are exposed to many variations of the product, and a set of terms is generated to describe differences among the products. Then, through consensus panelists develop a standardized vocabulary to describe sensory differences, and they decide on reference standards and/or verbal definitions that should be used to anchor the descriptive terms. Evaluations of panelist performance might also be used to ensure reliability of the evaluation. The product evaluations are performed by each panelist individually, usually in separated booths (Lawless & Heymann 2010).

4.1.2 Temporal Dominance of Sensation (TDS)

Temporal Dominance of Sensations (TDS) is a method for dynamic evaluation of perception, where dominant sensations are recorded during mastication (Lenfant et al. 2009). As shown in Figure 3a the panelists are given a list of attributes on the computer screen, and are told to click on the attribute perceived as dominant in the mouth. When the sensation is not dominant any longer, the panelist is free to select a new dominant attribute, until perception ends or until the product is swallowed (Pineau & Schilch 2015). Assessors need to continuously make a choice among several attributes to determine the sequence of dominant sensations.

Sometimes the intensity of the attributes is rated as well, however, ranking is not necessary as dominance rates alone can provide important temporal information (Di Monaco et al. 2014), and the panelists can concentrate better on the temporal aspects of the sample when intensity is not rated.

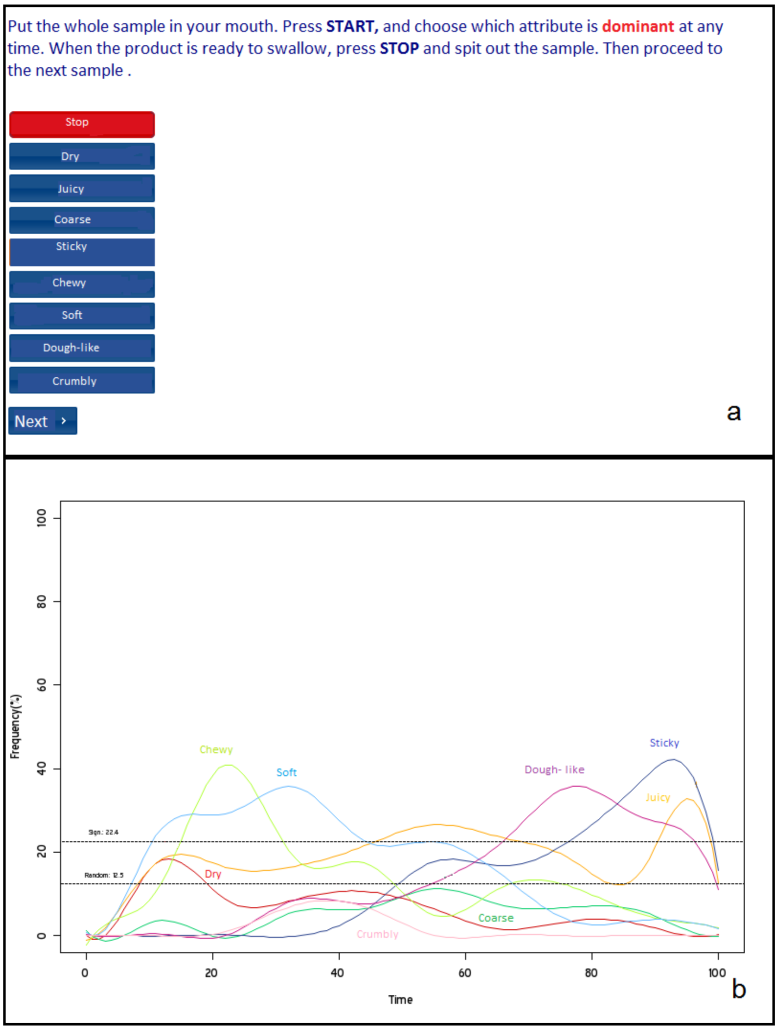


Figure 3. a) *TDS start screen. Assessors click on the attribute each time it is perceived as dominant in the mouth.* ***b)*** *TDS curve of results. Each line represents different attributes, measured as frequency (%) over time (0-100 standardized seconds) (source: EyeQuestion).*

During the tasting, the computer records the dominant attributes over time. To summarize the results and get a descriptive picture of each product, the most common representation is the TDS curve, as shown in Figure 3b. Thus, TDS is a multi- attribute method aimed at evidencing the sequence of dominant perceptions along tasting. TDS can be classified as a rapid sensory method, since it has the possibility to record temporal information on several sensory attributes during the same evaluation (Pineau & Schilch 2015).

4.2 Consumer testing

An affective test is typically performed by a sample of 75-150 consumers, who are regular users of the product (Lawless & Heymann 2010). Product profiles can be obtained from consumers, for example by a check-all-that-apply (CATA) question (Varela & Ares 2014).

4.2.1 Acceptance testing

One way of assessing the consumer's appeal to a product is to use a rating scale for degree of liking or disliking, known as acceptance testing. Contrary to preference tests, this method does not require a choice between alternatives and gives information on whether a product is liked or disliked instead of being preferred over another product. The most common hedonic scale is the 9-point scale. Responses on this scale are usually assigned values from 1 to 9, 1 for dislike extremely, and 9 for like extremely (Lawless & Heymann 2010). According to Blundell et al. (2010) many studies show that palatability has a strong effect on ad libitum food intake, so when studying the effect of particular food properties on satiation, it is important that the experimental foods are similarly liked.

4.2.2 Expected satiation and expected satiety

According to Blundell et al. (2010) it is possible that cognitive factors play an important role in meal termination. Based on the consumption of many thousand foods through our lifetime we gradually learn to estimate the satiating effect of many foods. These learning mechanisms determine our expectations about satiating properties of food, and probably also determine how much we put on our plate.

The learned associations between sensory attributes and metabolic consequences after consumption may be the basis of expectations relating to the satiating capacity of food. The expectations may depend on familiarity and appropriateness for the eating occasion, but might also differ between foods within one product category (Hogenkamp et al. 2011).

Brunstrom et al. (2008) found a highly significant association between actual satiety scores (calculated from satiety index scores) and expected satiety. Results on expected satiation and expected satiety are often highly correlated. (Brunstrom 2011) Blundell et al. (2010) stated that energy density of the product might play a crucial role in the learned response on satiation, so it is important to match foods for energy density when investigating the effect of food properties on satiation.

4.2.3 Check-all-that-apply questions (CATA)

CATA is a way of rapidly obtaining product profiles from consumers. Consumers are presented with a sample and a list of attributes, and are asked to indicate which words or phrases appropriately describe their experience with the sample. The terms might include sensory attributes as well as hedonic responses, emotional responses, purchase intentions, potential applications, or other terms that the consumer might associate with the sample, depending on the experimenter's interest (Varela & Ares 2014). Figure 4 shows an example of how a CATA question could be presented to a consumer.

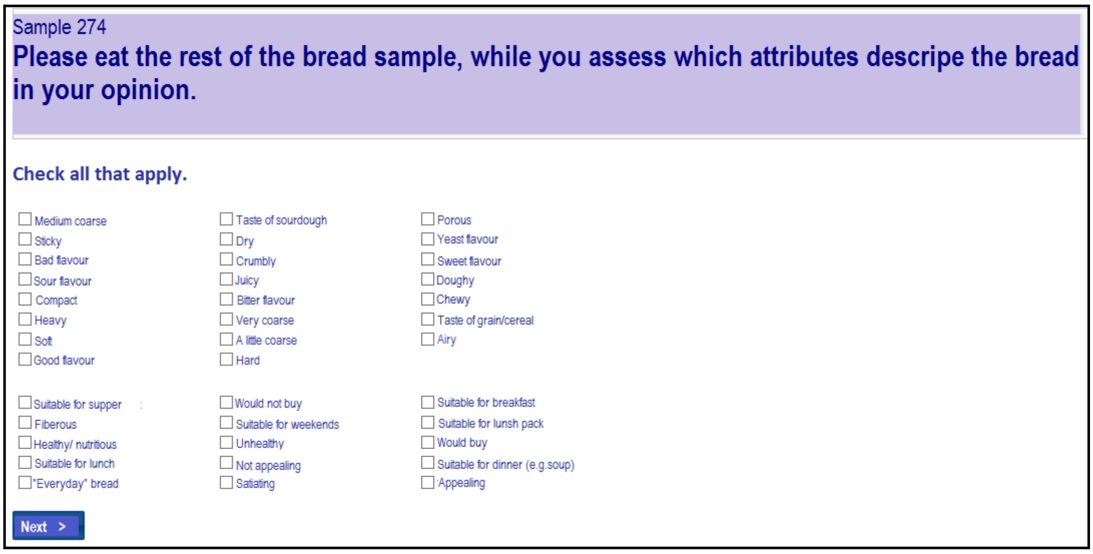


Figure 4. *CATA question. Consumers check which attribute describe the bread in their opinion (source: EyeQuestion).*

In order to relate CATA results to consumer acceptance, CATA studies are often accompanied with liking questions and might include the evaluation of an ideal product. CATA questions might be further combined with demographic and consumer psychographic questions, for example, to provide a so-called all-in-one test (Varela & Ares 2014).

5. Materials and methods

The food product used for the study was barley bread with different texture profiles. The procedure for manufacturing the samples is explained in the chapter below (see section 5.1). Methods for assessing the samples are explained as well, including Temporal Dominance of Sensations (section 5.2.1), Quantitative Descriptive Analysis (section 5.2.3) and a consumer test (section 5.4). The consumer test includes acceptance, expected satiation, expected satiety ratings, and product description for both the real samples and an ideal bread. The flow chart provides a simple overview of the study design.

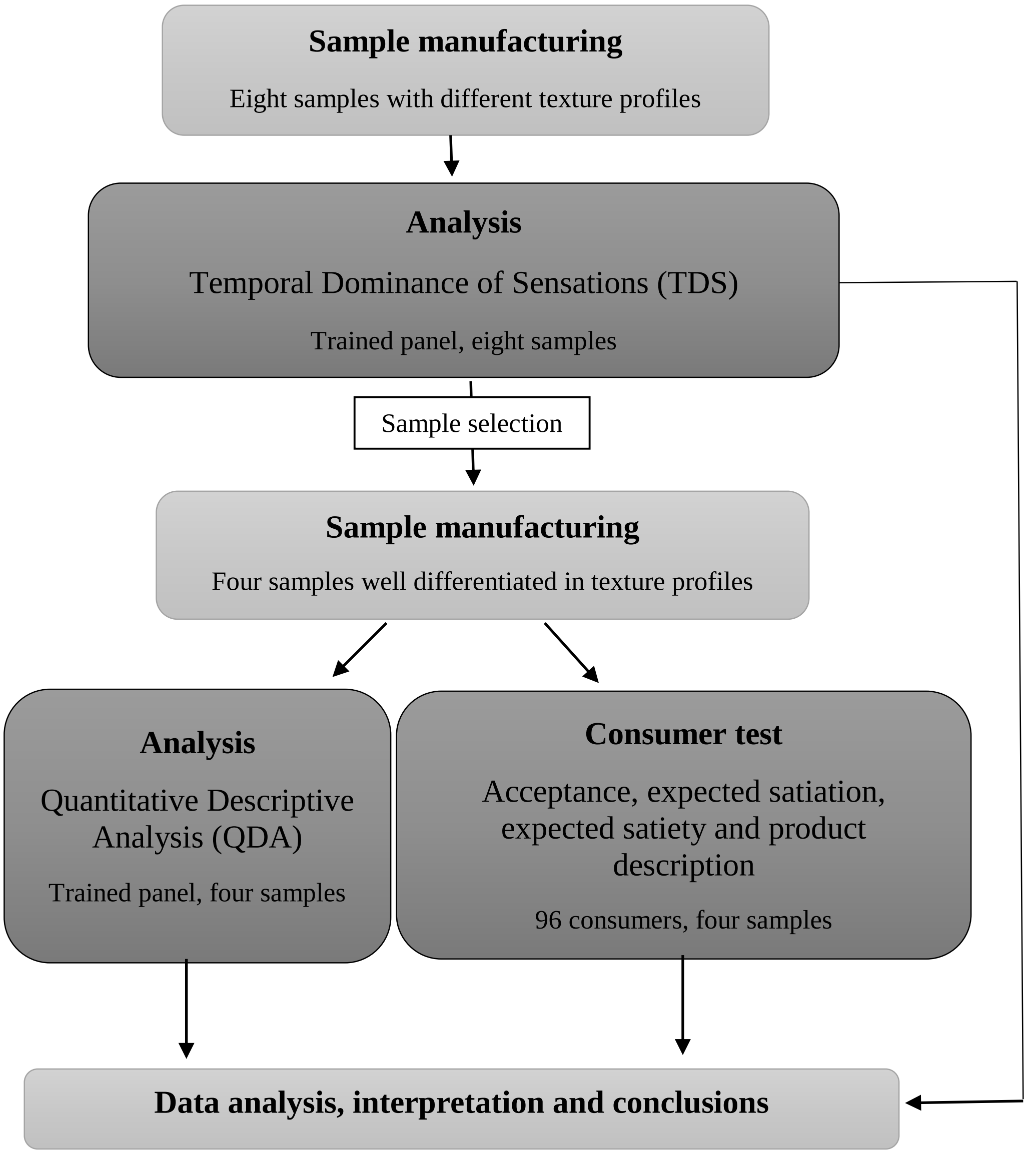


***Figure 5**. Flowchart of the study design for the master thesis.*

5.1 Bread samples

The food product used was barley bread made from a standard recipe (Table 1), with different processing on the barley. When studying the effect of particular food properties on satiation, it is important that the experimental foods are similarly liked and has the same energy density, as explained in section 4.2.1 and 4.2.2. A standard recipe was used for all samples in order to achieve samples similar in taste and caloric content.

Table 1. Standard recipe

With sourdough	Without sourdough
1300 g wheat flour	1400 g wheat flour
600 g barley	600 g barley
30 g salt	30 g salt
20 g active yeast	20 g active yeast
1000 g water for soaking or scalding	1000 g water for soaking or scalding
400 g water	500 g water
200 g sourdough	

The barley used was dehulled, from Ottadalen mølle, Skjåk, Norway. Barley grains were processed in four different ways: fine or coarse flour, and thin or thick flakes, as shown in figure 6. A hammer mill (Retsch 200) was used to make flour with sieve size 0.5 mm and 2.0 mm, and a flaking mill (Ferrell-Ross) was used to make thin (1.02 mm/0.025 in) and thick (2.54 mm/0.1 in) flakes.

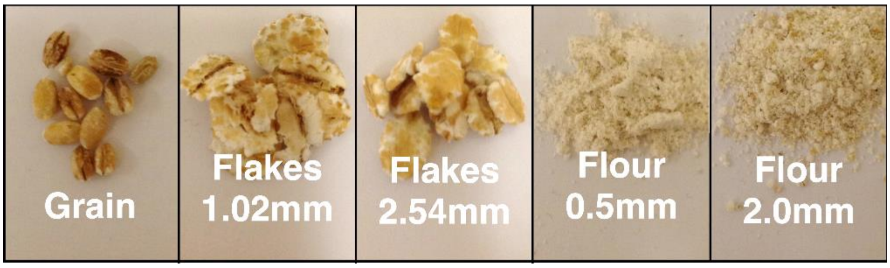


Figure 6. *Barley grains, thin and thick flakes and fine and coarse flour.*

The barley grains soaked in water overnight to achieve 20 % moisture content before being pressed into flakes. The flour and flakes were stored at 8^0C for a week before baking. Texture was manipulated further by scalding or soaking the barley and through fermentation where sourdough was added to some of the batches. Addition of sourdough has been reported to have a major effect on the dough and final bread structure (Arendt et al. 2007). The different processing on the barley was not expected to change the nutritional value of the breads, however the type (flour or flakes) and size (fine/thin and coarse/thick) of barley were expected to influence enzymatic activity, and therefore possibly the rate of digestion. Thick and coarse barley were expected to be more difficult to digest, and therefore be more satiating. The scalding were expected to make the starch more available for enzymes, and therefore the bread would be digested at a higher pace, indicating the breads added scalded barley would be less satiating (personal communication with Nofima's cereal department).

The baking took place on two different occasions, first in October 2014 to produce eight samples with different textural profiles, which were analyzed by using the dynamic sensory method Temporal Dominance of Sensations (TDS), and second in January 2015 to produce material for the Quantitative Descriptive Analysis (QDA) and the consumer test.

5.1.1 Manufacturing of breads 1-8

Eight different breads were made, based on an experimental fractional factorial design with four factors: barley type (flour or flakes), size (fine/thin or coarse/thick), treatment (soaking or scalding) and fermentation (yes or no), eight different breads were made (Table 2). Factor selection was conducted in cooperation with Nofima's baker and Nofima's cereal department with the purpose of generating samples with differentiated textural properties but with the same composition. For each type of bread, six loaves were made.

Table 2. Experimental design for baking process

Sample	Type	Size	Treatment	Fermentation
Bread 1	Flour	Fine/thin	Soaking	No
Bread 2	Flakes	Fine/thin	Scalding	No
Bread 3	Flour	Fine/thin	Scalding	Yes
Bread 4	Flakes	Coarse/thick	Scalding	Yes
Bread 5	Flour	Coarse/thick	Scalding	No
Bread 6	Flakes	Fine/thin	Soaking	Yes
Bread 7	Flakes	Coarse/thick	Soaking	No
Bread 8	Flour	Coarse/thick	Soaking	Yes

For the fermented samples, 100 g of water and 100 g of wheat flour were removed from the standard recipe, and 200g sourdough was added (see standard recipe in Table 1). The sourdough was fermented using 0.15 g Florapan L73, 500 g wheat flour and 500 g water, and was set to ferment at 25^{0}C (60% RH) overnight. When soaking, the barley flour or flakes were soaked in 1000 g of water (12^{0}C) for one hour before proceeding. For scalding, 1000 g of water (100^{0}C) was added, and cooled down overnight in room temperature. During both scalding and soaking the mixture was covered with plastic to prevent drying.

A bread prototype was made with commercial fine flour barley, to calibrate the dough mixer and test the standard recipe. The mixer (Diosna) was set at a slow pace (30 Hz) for 6 minutes, and fast pace (50 Hz) for 8 minutes. The resting time for the dough was set at 60 minutes at 25^{0}C (65% RH). Pans holding eight loaves at a time were used, and loaves weighed approximately 585 g each. The resting time for the loaves (when in the pan), was set at 45 minutes at 35^{0}C (65% RH). When placed in the oven, the loaves were steamed at 240^{0}C for 10 seconds, and then baked at 220^{0}C for 30 minutes.

The 500 g of water (400 g for the fermented breads) that was added after soaking (when placing all ingredients in the mixer) had to be colder and colder for each batch as the mixer generated more heat over time (friction from kneading). For some of the batches the mixing time was shortened to prevent the temperature from exceeding 27^{0}C. According to Nofima's baker, there is a bigger difference in the dough when temperature is too high, than if the mixing time is shortened (personal communication). The loaves cooled down without the pan, on a tray, and stood over night uncovered. As expected, there was a lot of difference in the appearance between the eight samples. Samples were sliced in 1.1 cm thick slices and packed in zip-lock bags with five slices in each bag. The slices were 1.1 cm thick to be similar to commercial bread in order to seem familiar for the consumers. The ends of the loaves were discarded and the slices from the middle part of the loaves were used for TDS and instrumental analysis. The slices were frozen after 24 hours (+/- 30 min) at -20 ^{0}C.

5.1.2 Manufacturing of breads for QDA and consumer test

For the consumer test and the QDA four different types of bread were made (twelve loaves of each) using the same baking ingredients, materials and procedure as for the breads used in TDS. Breads 3, 5, 6 and 7 (table 2) were chosen for the QDA and consumer test based on the results from the TDS analysis, as they were the most different in dynamic texture profile (see section 6.2.1).

When baking, the batch was doubled for each type of bread in order to have enough material for the QDA and the consumer test. For breads 3 and 5 the temperature got higher than expected during the mixing, this resulted in loaves different from those made in October. Another baking was conducted for these samples, where barley flakes and flour were cooled down to 6.6^{0}C. These doughs had approximately the same temperature and mixing time as the loaves made for the TDS, and were visually similar.

Analysis of data for each sample.

For breads 1-8, dough temperature, weight of doughs and slices, and moisture content were measured. Volume of the loaves was measured as well, using the instrument BVM 6630 (Perten Instruments). The average firmness of all samples was analyzed with the Texture Analyzer XT plus (Stable Micro Systems). Images of slices were obtained using C-cell (Calibre Control International Ltd.). ANalysis Of VAriance (ANOVA) is a useful methodology for looking at product differences in sensory and consumer studies. ANOVA identifies and quantifies the factors responsible for the variability of the response (Næs et al. 2010). In the statistical software Minitab® 17, ANOVA was used to compare averages for the different samples. Tukey Pairwise Comparison was performed to see which samples were significantly different from each other. Weight and temperature of the doughs were not analyzed using ANOVA due to lack of replicates.

5.2 Sensory testing

To assess the sensory attributes for the bread samples, two analyses with a trained panel were performed. Temporal Dominance of Sensations (TDS) was chosen to see how the samples are perceived during oral processing, and Quantitative Descriptive Analysis (QDA) to obtain a detailed description of the samples used for the consumer test. Both analyses were conducted in a sensory laboratory, which meets the requirements set in ISO 8589:2007. The laboratory has individual booths, standard lighting and a separate ventilation system. The panelists are chosen based on abilities that meet the requirements set in ISO 8586:2012.

5.2.1 Temporal dominance of sensations (TDS)

The TDS was performed on eight different samples, over a period of two days. Ten assessors from Nofima’s trained sensory panel attended. Two pre-tests and a brainstorming were conducted prior to the main trial. The software EyeQuestion was used for data collection.

Practical aspects: The bread was defrosted at room temperature for three hours prior to preparation. Samples were served at room temperature in circular pieces with a 3.7 cm radius, 1.1 cm thick. A lid was placed over the samples directly after cutting to prevent drying. The general rule was to cut a piece without crust, in the center of the slice and to avoid big holes to make sure the sample was big enough.

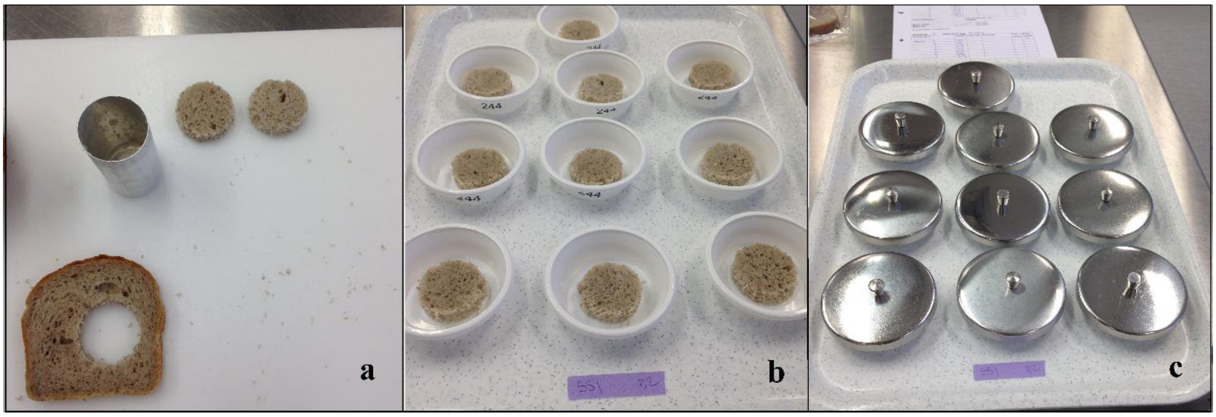


Figure 7. *Sample preparation for the TDS.* ***a****) Samples were cut in circular pieces, avoiding big holes and the crust,* ***b)*** *samples were served in coded plastic cups,* ***c****) covered to prevent drying****.***

The panelists were instructed to put the whole sample in their mouth at once. Dominance of attributes alone, without intensity ratings, was collected.

<u>Pre-test 1</u>

A pretest was run to trial the evaluation procedure and sample size in mouth. Some of the assessors found it difficult to swallow the sample, and thought the focus shifted from attributes to swallowing. The assessors are trained to spit out samples in sensory evaluation, therefore spitting might feel more natural than swallowing. One of the panelists thought it would be difficult to swallow all the samples because of the increase in satiation. There was an agreement among assessors not to swallow samples. For the oral processing, instructions were; "*chew and evaluate until the sample is ready to swallow, press stop, and spit out the sample*". The panelists accepted the sample size.

<u>Brainstorming</u>

The goal of the brainstorming was to agree on 8-10 attributes for the TDS, focusing on texture in mouth. The assessors were given a list of 11 attributes for texture in bread, and 9 flavor attributes, as presented in Table 3. The attributes chosen for the brainstorming were gathered from previously used attributes for bread at Nofima AS, and from literature (Pineau et al. 2012; Szczesniak 2002)

When choosing attributes for TDS all the potential dominant attributes must be there, and the list needs to be short enough for the subjects to handle. According to Pineau et al. (2012) a long attribute list (>10 terms) does not seem to be used in an optimal way by the subjects because all the attributes are not used. Suggestions for new attributes not mentioned in the list were allowed to make sure all relevant attributes were included.

Table 3. Suggested attributes for brainstorming			
Texture		**Flavor**	
Chewy	Juicy	Bitter	Salty
Coarse	Moist	Grains	Sour
Cohesive	Springiness	Nut/seed	Sweet
Fracturability	Sticky	Rancid	Yeast
Grainy	Toughness	Roasted	
Hard			

The panelists were provided with two of the visually most different samples and the list of attributes, and then there was a collective discussion under the guidance of the panel leader. The discussion resulted in the addition of terms *dryness* and *porous* and a clarification of terms *grainy* and *coarse*.

Pre-test 2

A second pre-test was conducted to further adjust the attribute list. The final attribute list had eight attributes, all on texture in mouth, as shown in Table 4. The assessors all agreed on the attributes and procedure after the last pre-test.

Table 4. Final attribute list for TDS	
Texture	
Chewy	Dry
Coarse	Juicy
Crumbly	Soft
Dough- like	Sticky

Main trial

The main trial started with a short meeting, discussing the schedule for the day and reminders of the procedure. There was also a short review of the attribute list. The panelists all agreed on the attribute list and the schedule before we started the trial. The assessors were served a “warm up” round with an average sample before the main trial because the brainstorming and main trial were on separate days. Samples of breads 1-8 were served in small plastic cups marked with a three-digit code. The samples were evaluated in triplicates. The eight samples were served at a time, in randomized order.

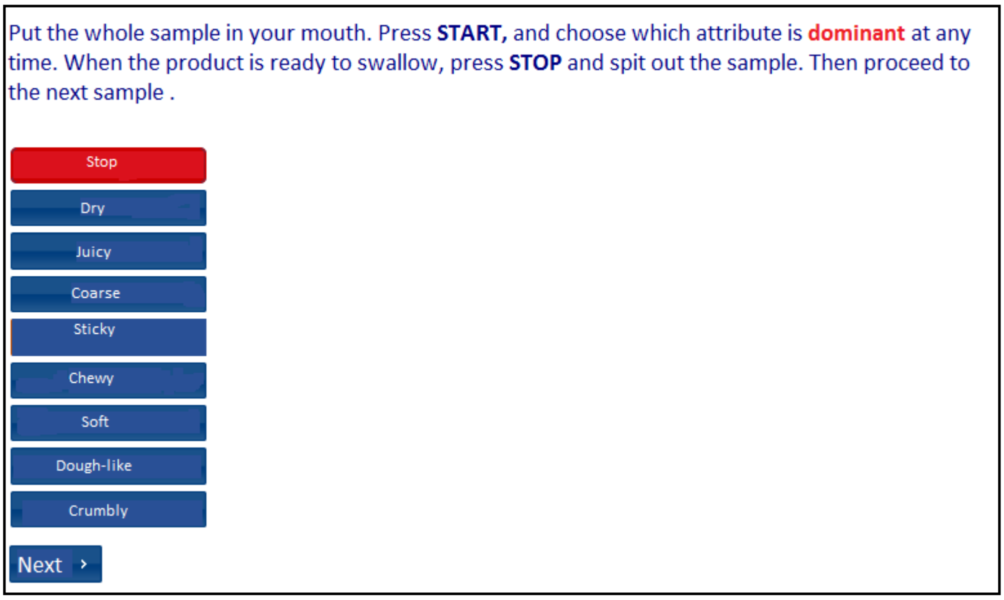


***Figure 8**. TDS screen. Assessors were instructed to put the sample in their mouth and press start, then to check an attribute every time it was perceived as dominant in the mouth.*

A one-minute non-optional break was added between samples, and a five-minute break for every third sample. There was a 15 minute break between the two last servings. It took about 15 minutes to prepare for each serving, and each set took approximately 30 minutes to complete.

Analysis of TDS data

Results were obtained from EyeQuestion (Logic8 BV, Netherlands) and presented as TDS curves. This is the most common presentation of TDS results (Pineau & Schilch). One curve is obtained for each attribute, and the graph shows which attribute is dominant at any time. In the trial, assessors were allowed to masticate at their own rate. This can be problematic when analyzing the results. Since mastication behavior and mastication duration differ between subjects, time scales of sensory perception differ as well. To consider this in the computation of TDS curves, results were standardized from the first scoring to swallowing, to correct for individual mastication durations. After standardization, the X-axis represents the period from first scoring to swallowing, instead of real time (Lenfant et al.). Consequently, all TDS curves are shown from 0 to 100 standardized "seconds".

5.2.3 Quantitative descriptive analysis (QDA)

Eight assessors from the trained panel at Nofima conducted the Quantitative Descriptive Analysis (QDA) on breads 3, 5, 6 and 7. The samples were defrosted at room temperature before preparation. The panelists were served two pieces of a sample at a time, cut into a square sample, avoiding the top of the slice and the crust. The pieces were approximately 5*3*1.1cm. The samples were served in plastic cups, marked with a three-digit code and covered with a lid to prevent drying (Figure 9).

Figure 9. *QDA preparation. Samples were served in coded plastic cups, covered to prevent drying.*

Before the main trial, panelists were calibrated in a pre-trial using bread 6 and 7, and a list of attributes was provided. After the pre-trial, attributes and intensity ratings were discussed collectively. Samples of breads 5 and 3 were provided for the discussion to represent the different variations of samples.

Table 5. Attributes QDA

Flavor	**Texture**
Bitter	Chewy
Cloying	Dough-like
Grainy	Crumbly
Raw	Porous
Salty	Coarse
Sour	Hard
Sweet	Juicy
Yeast	Sticky

The software PanelCheck (V 1.4.0) was used to assess panelist performance during the pre-trial, to see if adjustments should be made before the main trial. Attributes *cloying* and *raw* flavor were added. The main trial was conducted with two replicates in three sessions (3+3+2). The final attribute list had eight flavor and eight texture attributes as presented in table 5. In descriptive analysis, assessors generate a scaled response to the attributes to reflect the intensity (Lawless & Heymann 2010). Attribute intensity were registered using unstructured line scales with labeled endpoints, ranging from “None” to “Distinctly” (Figure 10).

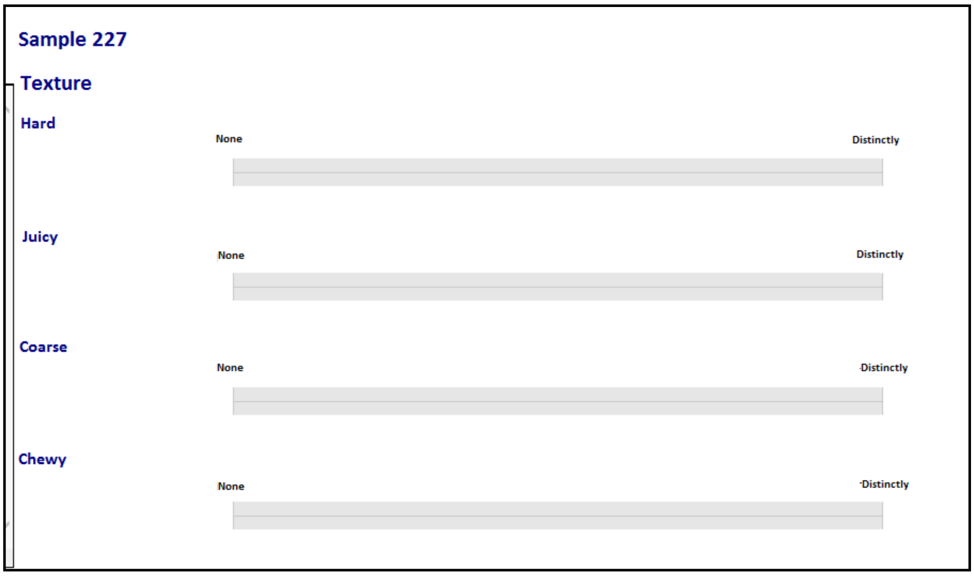


Figure 10. *Unstructured scales used for QDA, with intensity ranging from "None" to "Distinctly".*

<u>Analysis of QDA data</u>

The software EyeQuestion was used for data collection. Results were analyzed using 2-way ANOVA in the software PanelCheck. In Minitab, Tukey pairwise comparison was used to assess significant differences between products.

5.3 Consumer testing

A quantitative consumer test was conducted at Nofima AS, Ås, in February 2015, and was completed in one day. The consumers evaluated four bread samples selected based on the TDS results (see section 6.2.1). They rated acceptance, expected satiety and expected satiation for the samples, and provided a product description in a check-all-that-apply (CATA) question. In addition, statements regarding bread, health and satiety were evaluated.

5.3.1 Recruitment

108 consumers (Table 6) were recruited from leisure time organizations in the area. The age of the consumer might have an influence om attitude to and appreciation on texture, as teenagers have a higher awareness of texture, and older people might have difficulties chewing either because of poor dentition, or because of weak muscles and poor coordination (Szczesniak 2002). Age might also influence appetite ratings (Gregersen et al. 2011). Therefore, it was decided only to include adults between the age of 18 and 40 years. Another factor that might influence appetite ratings are gender (Gregersen et al. 2011). Bias due to gender differences was considered in the recruitment process by recruiting as equally as

possible between genders. No subjects on a diet, with celiac disease/gluten intolerance or aversion to wheat/barley were recruited. Pregnant and lactating women were excluded, as they might have altered eating habits and satiety regulation (Rosso 1987). Participants had to like coarse bread, and consume bread 2-3 days a week or more.

Table 6. Recruited consumers		
Consumers (n)		108
Gender	F	63
	M	45
Age		18-40
BMI (kg/m²)		18.0-29.9

Only participants with Norwegian as first language were recruited, to avoid misunderstandings when conducting the trial. To avoid affecting the senses, consumers were instructed not to eat anything during two hours before they arrived and no to chew gum, smoke tobacco or drink coffee 30 min before participating in the test. They were also instructed not to wear perfume. In total 96 consumers completed the test, 51 females and 45 males. The participants received 200 NOK to leisure time organizations for participating.

5.3.2 Practical aspects

The samples defrosted at room temperature for three hours before sample preparation. The consumers were served two pieces of each sample, which was approximately 5*3*1.1cm. Samples were served in plastic cups with aluminum foil to prevent sample dryness and to avoid visual comparison between samples (Figure 11a).

***Figure 11. a)** Samples were served in coded plastic cups, covered with aluminum foil. **b)** Individual booths.*

The plastic cup and aluminum foil were marked with a three-digit code identifying the sample. The consumers sat in separate booths (Figure 11b), and received a tray with all four samples at once. Consumers were instructed to eat one of the sample pieces for acceptance, expected satiation and expected satiety ratings, and one piece for the CATA- questions. Consumers were invited to drink water in between samples. All samples were randomized in balanced order.

5.3.3 Questionnaire

Consumers were told to follow the on-screen instructions in the questionnaire in EyeQuestion. All questions were presented in Norwegian.

The structure of the questionnaire was:

1. Current level of hunger
2. Acceptance for the four samples
3. Expected satiation and expected satiety for the four samples
4. CATA question for the four samples
5. CATA for the ideal bread
6. Statements regarding bread, health and satiety
7. Demographics and habits regarding bread consumption

If practical, it is recommended to place acceptance questions before CATA questions in case CATA questions affect the liking scores. When evaluating an ideal by using the same attributes as for the real product, the questions for the ideal product should always be placed after the real samples (Varela & Ares 2014).

1. Current hunger level

Before assessing samples, consumers were asked to rate their current level of hunger on a 100mm line scale, ranging from “Not hungry at all” to “Very hungry”, as presented in Figure 12. The reason for asking this question was to be able to assess if the participants hunger level when attending the consumer test influenced the expected satiation ratings.

<u>Analysis of current hunger level data</u>

EyeQuestion was used for data collection, and hunger ratings were separated in to hunger levels, and compared to expected satiation as shown in section 6.3.3.

Figure 12. *100mm line scale, ranging from "Not hungry at all" to "Very hungry".*

2. Acceptance

Acceptance rating provides information on the sensory appeal of the product, whether it is liked or not, as opposed to preference testing, which gives information on consumers' choice between samples (Lawless & Heymann 2010). The purpose of the question was to see if there was a difference in liking, as palatability might affect the results for the satiety questions (Blundell et al. 2010). Acceptance is also a common question in combination with CATA questions (Varela & Ares 2014), in order to build a prefmap.

All samples were randomized across assessors. For each sample consumers were asked; "*how much do you like this bread?"* Acceptance was rated on a modified 9-point scale, ranging from 1= "I don't like it at all" to 9= "I like it very much". The 9- point scale is the most common hedonic scale, and is usually assigned values from 1-9, 1 for dislike extremely and 9 for like extremely (Lawless & Heymann 2010).

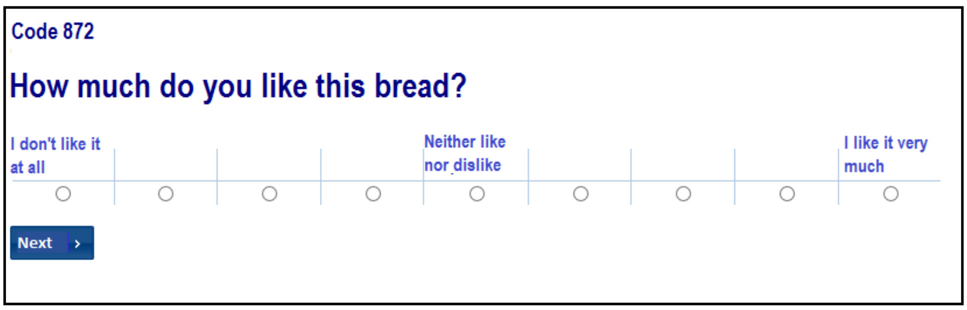


Figure 13. *Modified 9-point scale for rating acceptance, ranging from "I don't like it at all" to "I like it very much"*

<u>Analysis of acceptance data</u>

Data collection was conducted in EyeQuestion, and analyzed in MiniTab using ANOVA and Tukey Pairwise Comparison.

Expected satiation and expected satiety

Brunstrom et al. (2008) found a highly significant association between actual satiety scores (calculated from satiety index scores) and expected satiety. Choosing expected satiety as a method for this study allowed more consumers to participate, as it is less time-consuming and possibly more cost-efficient than an actual satiety study. According to Hogenkamp et al. (2011) satiety expectations may differ between foods within one product category, and the method should therefore apply for the material used in this study.

All samples were randomized across assessors. For questions regarding expected satiation and expected satiety, an introduction was added to EyeQuestion. Consumers were told to imagine having a typical Norwegian open-sandwich meal with the same type of topping and the same number of bread slices they normally eat. The question regarding expected satiation was rated on a 9- point scale, ranging from 1=”Not full at all” to 9= “Very full”, asking: “How full do you think you would get eating this bread?” For expected satiety they were asked to rate how long they would feel full from this bread, on a 6-point scale from 1=“hungry again at once” and up to 6=“Full for five hours or longer”.

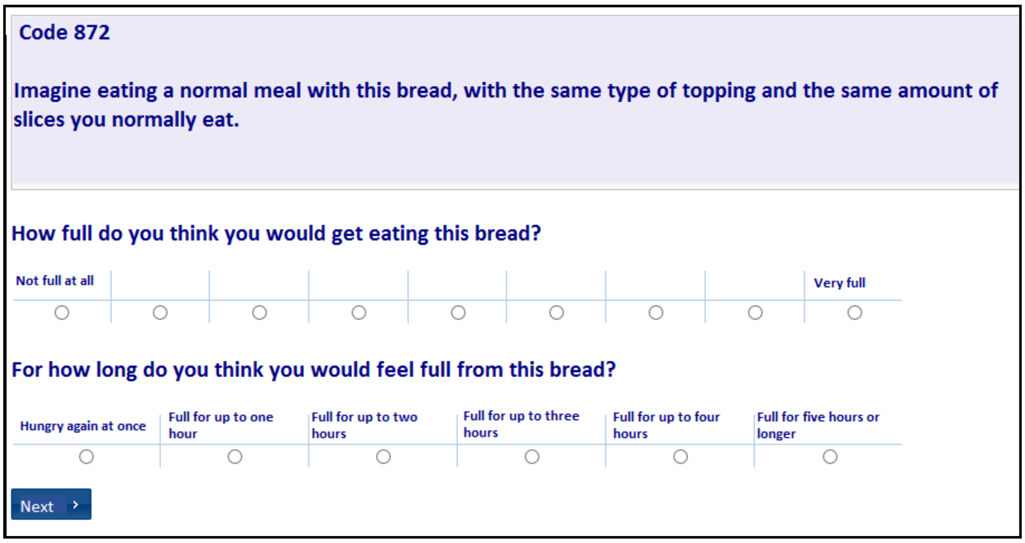


Figure 14. *Satiation and satiety question (text is translated from Norwegian)*

<u>Analysis of expected satiation and satiety data</u>

EyeQuestion was used for data collection and data was analyzed in Minitab by ANOVA and Tukey Pairwise Comparison.

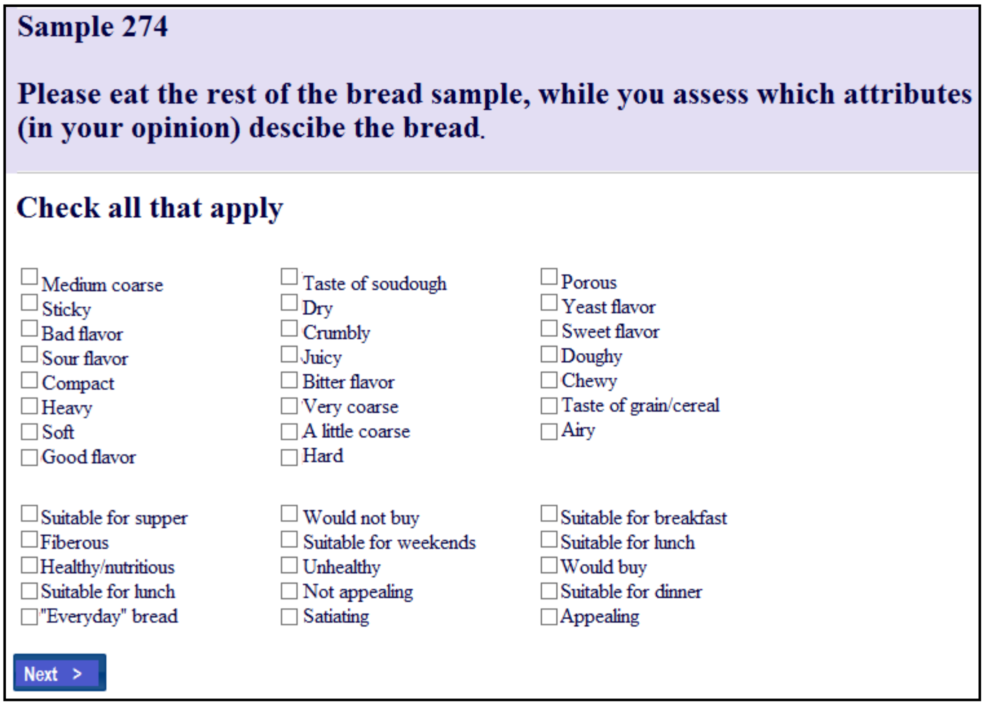
3. CATA real samples

The CATA questions for breads 3, 5, 6 and 7 were randomized across samples and assessors. It is typical for CATA studies to be conducted as a full crossover where each assessor evaluates each sample in a sequential monadic presentation. To avoid bias it is recommended to balance the order of products across consumers (Varela & Ares 2014).

A single CATA question might include different types of attributes. Some studies have successfully included more than 40 attributes at the same time (Varela & Ares 2014). For this study, there were 23 sensory and 15 usage attributes (Table 7). CATA attributes were identical for both the real bread samples and the ideal bread.

Table 7. Attributes CATA		
Sensory attributes		**Usage attributes**
Flavor	**Texture**	"Everyday" bread
Bad flavor	Airy	Appealing
Bitter flavor	Chewy	Fiberous
Good flavor	Compact	Healthy/nutritious
Grain/cereal flavor	Crumbly	Not appealing
Sour flavor	Doughy	Satiating
Sweet flavor	Dry	Suitable for breakfast
Taste of sourdough	Hard	Suitable for dinner
Yeast flavor	Heavy	Suitable for lunch
A litte coarse	Juicy	Suitable for lunch pack
Medium coarse	Porous	Suitable for supper
Very coarse	Soft	Unhealthy
	Sticky	Weekend bread
		Would buy
		Would not buy

The position of the attributes within the CATA list can bias the consumers’ responses, therefore it is recommended to randomize the CATA attribute list between products and assessors. If a list consists of different groups of attributes, the grouping should be maintained during randomization (Varela & Ares 2014). For the consumer test the CATA attributes were separated into two groups, sensory attributes and usage attributes. All terms were randomized within groups.



Sample 274

Please eat the rest of the bread sample, while you assess which attributes (in your opinion) descibe the bread.

Check all that apply

☐ Medium coarse	☐ Taste of soudough	☐ Porous
☐ Sticky	☐ Dry	☐ Yeast flavor
☐ Bad flavor	☐ Crumbly	☐ Sweet flavor
☐ Sour flavor	☐ Juicy	☐ Doughy
☐ Compact	☐ Bitter flavor	☐ Chewy
☐ Heavy	☐ Very coarse	☐ Taste of grain/cereal
☐ Soft	☐ A little coarse	☐ Airy
☐ Good flavor	☐ Hard	
☐ Suitable for supper	☐ Would not buy	☐ Suitable for breakfast
☐ Fiberous	☐ Suitable for weekends	☐ Suitable for lunch
☐ Healthy/nutritious	☐ Unhealthy	☐ Would buy
☐ Suitable for lunch	☐ Not appealing	☐ Suitable for dinner
☐ "Everyday" bread	☐ Satiating	☐ Appealing

Next >

Figure 15. *CATA question, with 23 sensory and 15 usage attributes (text translated from Norwegian).*

<u>Analysis of CATA data</u>

Using the statistical software for Excel XLSTAT, CATA data was summarized in a contingency table showing the total counts each attribute was checked for each sample. A Cochran's Q test was performed to see which attributes were significantly different between samples. This test is widely used in CATA context for statistical inference of product differences by attributes (Varela & Ares 2014). If a consumer does not select an attribute, one should not conclude it does not apply for the product. It might also be because the consumer are neutral or undecided about it, or because they did not pay attention to it (Varela & Ares 2012).

4. CATA for the ideal bread

The CATA attributes used for the ideal bread were identical to the attributes used for real samples. When an attribute is selected for both a real sample and the ideal, it does not necessarily indicate that any of the real samples are ideal for the consumer, only that the chosen attribute applied for both the sample and the ideal (Varela & Ares 2014).


We want you to imagine you **ideal** bread

Check all atributes that describe your ideal bread

☐ Medium coarse	☐ Taste of soudough	☐ Porous
☐ Sticky	☐ Dry	☐ Yeast flavor
☐ Bad flavor	☐ Crumbly	☐ Sweet flavor
☐ Sour flavor	☐ Juicy	☐ Doughy
☐ Compact	☐ Bitter flavor	☐ Chewy
☐ Heavy	☐ Very coarse	☐ Taste of grain/cereal
☐ Soft	☐ A little coarse	☐ Airy
☐ Good flavor	☐ Hard	
☐ Suitable for supper	☐ Would not buy	☐ Suitable for breakfast
☐ Fiberous	☐ Suitable for weekends	☐ Suitable for lunch
☐ Healthy/nutritious	☐ Unhealthy	☐ Would buy
☐ Suitable for lunch	☐ Not appealing	☐ Suitable for dinner
☐ "Everyday" bread	☐ Satiating	☐ Appealing

Next >

Figure 16. *Question regarding the consumers ideal bread (text translated from Norwegian).*

5. Statements regarding bread, health and satiety

Consumers were asked to rate how much they agreed or disagreed on four statements regarding bread, health and satiety, on a 9-point scale ranging from 1= "totally disagree" to 9= "totally agree". The question was; "*How much do you agree/disagree on these statements?*" The statements were: 1) When I buy/bake bread I think about how satiating the bread is, 2) White bread is as healthy as coarse bread, 3) If I am going to get properly satiated, it is crucial that the bread is coarse, 4) When eating white bread, you need more slices to get satiated than if you eat coarse bread.

<u>Analysis of statements</u>

The data collection was obtained in EyeQuestion.

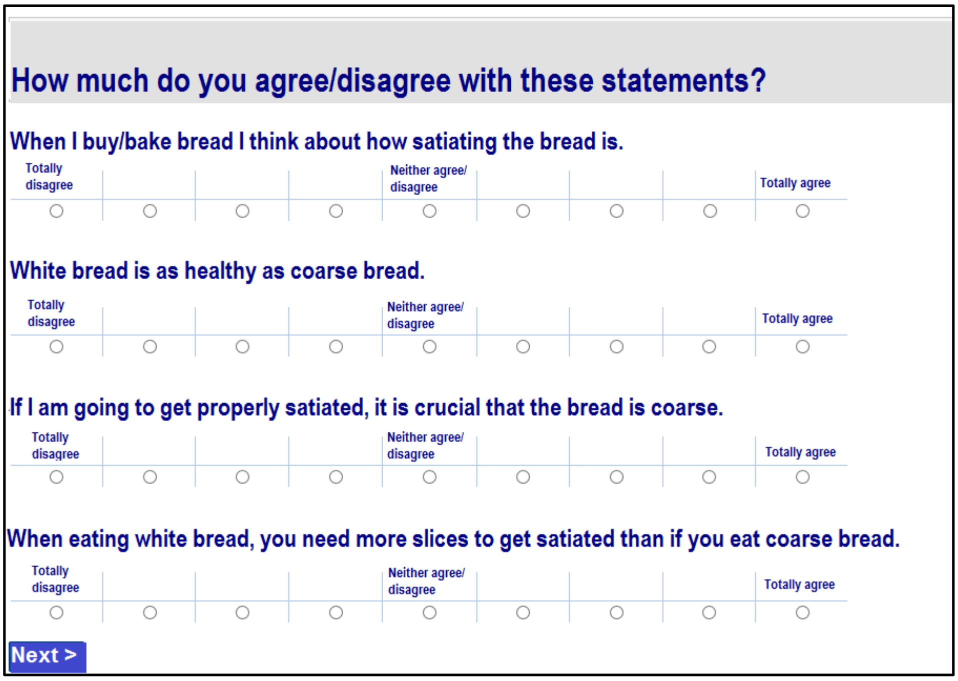


Figure 17. *Statement question (text translated from Norwegian).*

6. Demographics and habits regarding bread consumption

After completing the statements, consumers were asked to answer eight demographic questions. The questions were; 1) gender, 2) age, 3) height, 4) weight, 5) education level, 6) if they were students or employees, 7) how many days a week they ate bread, 8) to which meal they normally ate bread (breakfast, lunch, dinner, supper, snack).

6. Results

In this chapter, the instrumental data for the different breads, results from the trained panel and the consumer test are presented.

6.1 Instrumental results

For breads 1-8, weight and temperature of the doughs, loaf volume, slice weight and moisture content were measured. ANalysis Of VAriance (ANOVA) for breads 1-8 showed significant differences in volume, slice weight and moisture content. Tukey Pairwise Comparison showed that for volume, bread 3 was significantly different from the other samples, and was the least voluminous bread. Bread 6 was also significantly different from the other samples, and was the most voluminous bread (Table 8). For slice weight, breads 1 and 8 (the lightest slices) were significantly different from bread 2 (most heavy slice). The Tukey test shows that for moisture content breads 1, 3, 5 and 8 were significantly different from breads 2, 4, 6 and 7, with the latter group presenting higher moisture levels. Thus, the breads with lower moisture content were made with barley flour only, and the breads with the highest moisture content were made with barley flakes (Table 2).

Table 8. Data for breads 1-8

Sample	Weight dough, g	Loaf volume, cm^3	Slice weight, g	Moisture content, %
Bread 1	585.0	1523.5 (ab)	26.2 (b)	48.8 (c)
Bread 2	584.0	1184.5 (d)	32.3 (a)	49.8 (b)
Bread 3	582.3	1070.7 (e)	32.0 (ab)	48.5 (c)
Bread 4	584.0	1476.2 (b)	27.6 (ab)	50.4 (a)
Bread 5	583.0	1164.8 (d)	30.4 (ab)	48.8 (c)
Bread 6	585.0	1582.7 (a)	27.9 (ab)	50.0 (ab)
Bread 7	585.0	1280.2 (c)	28.2 (ab)	50.0 (ab)
Bread 8	588.0	1528.0 (ab)	26.3 (b)	48.8 (c)

Visual description of bread 1-8

Figure 18 shows images of the eight samples. Breads 1, 4, 6 and 8 were similar in size, however they differed in how airy they looked. Breads 3, 5 and 7 were the smallest samples. Breads 4 and 7 looked more airy than the other samples, bread 3 looked most compact and bread 7 looked the coarsest. Breads 1, 6 and 8 were visually the samples that looked most like commercial bread.

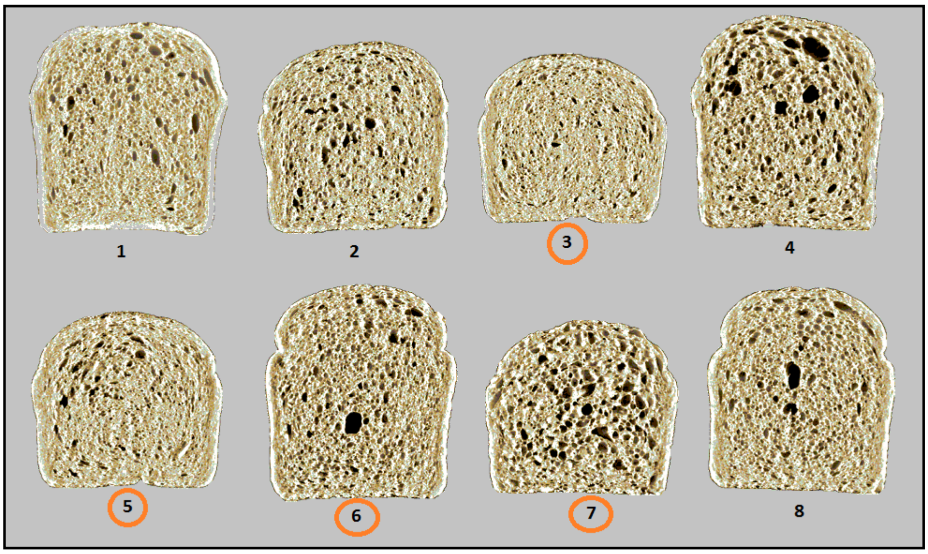


Figure 18. *Photos of samples 1-8. Breads marked with an orange circle were chosen for further analysis (based on results from TDS, see section 6.2.1).*

Analysis of data from the Texture Analyzer

The Texture analyzer showed that bread 3 was the most firm sample, and Tukey Pairwise Comparisons showed that bread 3 was significantly different from the other samples (Figure 19). Breads 4 and 6 were not significantly different from each other, and were the least firm samples.

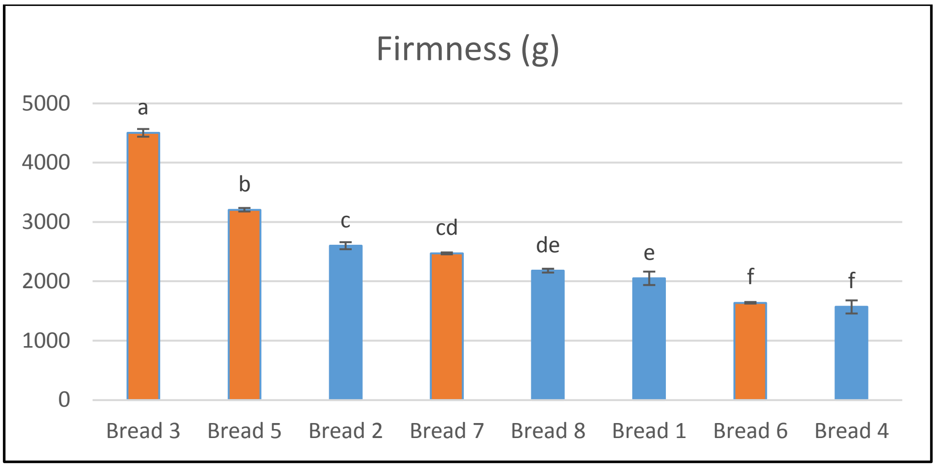


Figure 19. *Average firmness, presented from the most to the least firm samples. Orange columns represent samples chosen for further analysis, based on TDS results (section 6.2.1). Breads that do not share the same letter are significantly different from each other.*

6.2 Sensory testing

To assess the sensory attributes for the bread samples, Temporal Dominance of Sensations (TDS) and Quantitative Descriptive Analysis (QDA) were performed by a trained panel. In sections 6.2.1 and 6.2.2, results from the TDS and QDA are presented.

6.2.1 Temporal dominance of sensation (TDS)

The TDS was performed on samples 1-8 to see how they were perceived during oral processing. From these results, four breads with clearly different texture properties were chosen for further analysis. The assessors' oral processing time for each product was analyzed by 2-way ANOVA and a Tukey pairwise comparison test, and was found significantly different between products (Figure 20). Breads 6 and 8 had the shortest average oral processing time (27.5 and 27.8 seconds), and breads 3 and 5 had the longest oral processing time (31.4 seconds). The shortest oral processing time reported was 14.7 seconds (bread 4), and the longest was 68.6 seconds (bread 5).

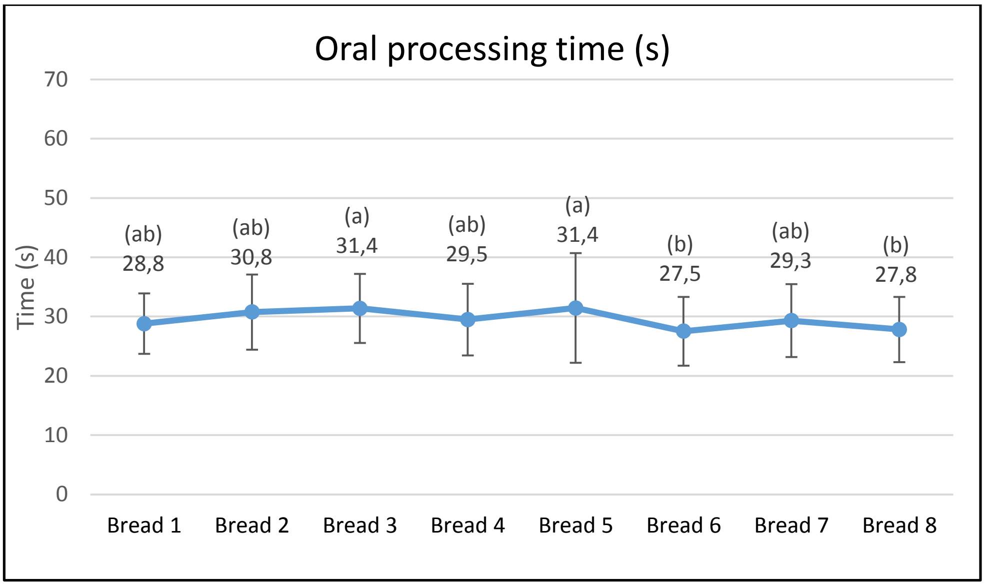


Figure 20. *Average oral processing time for breads 1-8. Breads that do not share a letter were significantly different from each other.*

To ensure comparable time scales across assessors, oral processing times were standardized to 100 seconds, as explained in section 5.2.1. In the results below all reported times are standardized times from 0-100 seconds. The TDS curves presented in Figures 21 and 22 show the frequency of dominance for each attribute during oral processing, presented as time in standardized seconds ranging from 0-100 seconds (x-axis) and frequency in percentages (y-axis). When analyzing the TDS curves, the significant level is reached for values above 22.4 % of the frequency (upper dotted line in the figure).

Bread 1

The TDS curve for bread 1 shows that attribute *dry* was perceived as dominant 10 seconds (standardized time) after start, decreasing after approximately 20 seconds, and was no longer significantly dominant after 55 seconds. Attributes *sticky* and *juicy* were perceived at the end of the oral processing. Other textural attributes were not above the significance limit.

Bread 2

Bread 2 had, according to the TDS curve, a variation in significant attributes during oral processing. The attribute *chewy* was perceived as dominant after approximately 20 seconds, and lasted for 15 seconds. The sample was perceived as *soft* after 15 seconds, increasing for 20 seconds and then declined, and as *juicy* in the middle of the oral processing. At the end of mastication, after approximately 70 seconds, the attribute *dough-like* appears, declining

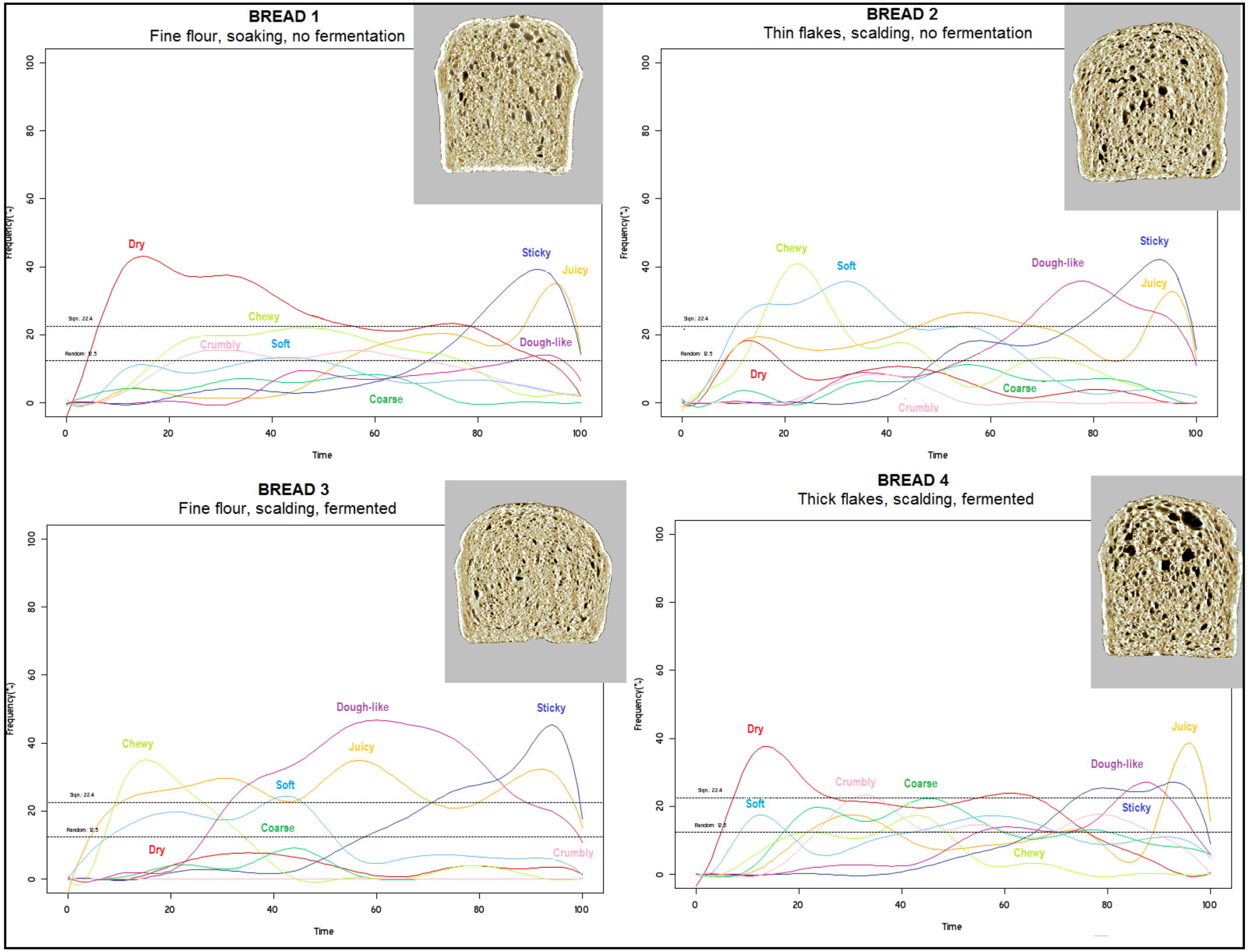


Figure 21. *TDS curves for breads 1-4. The x-axis show time (s) and the y-axis show frequency (%). Each line represent a different attribute.*

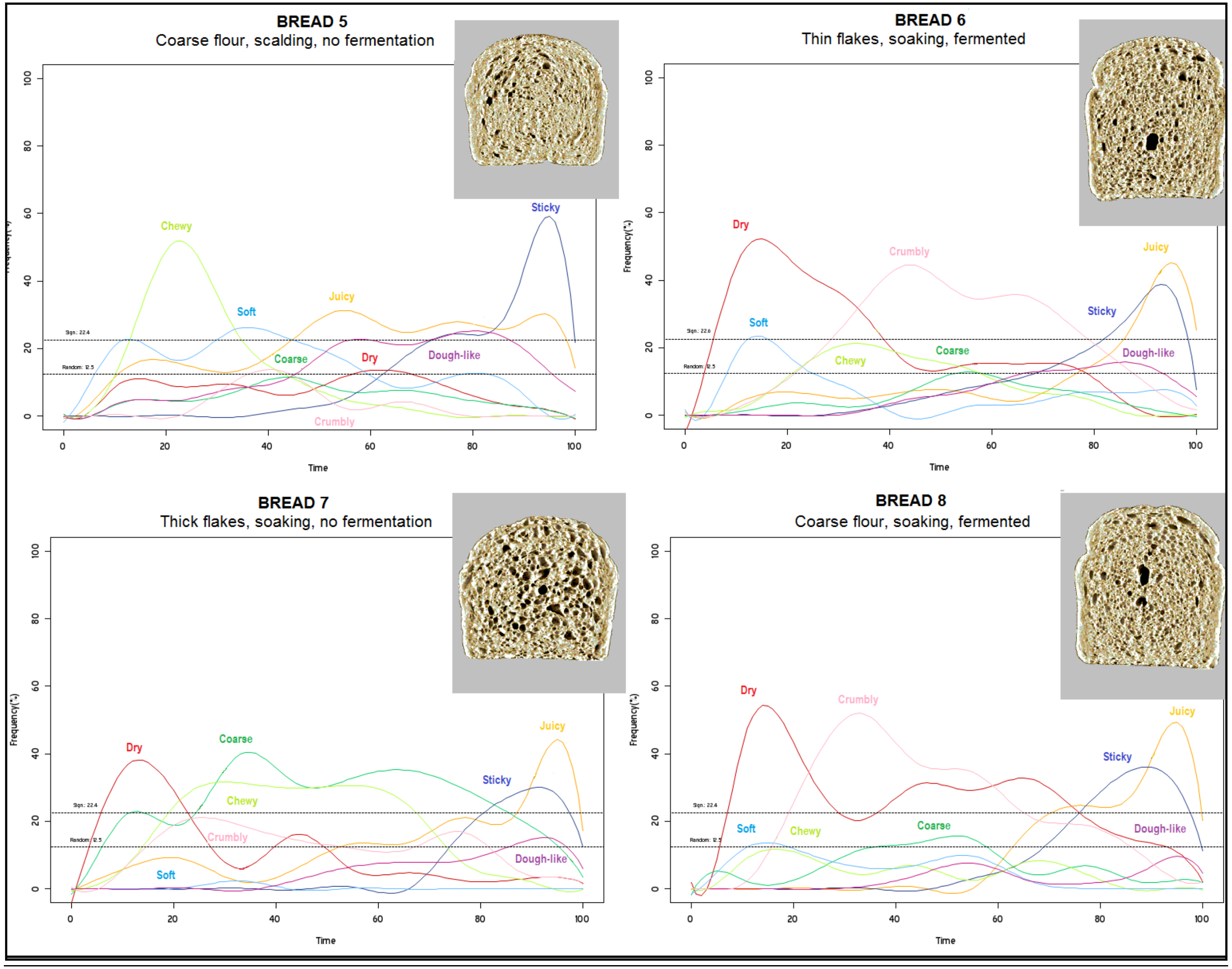


Figure 22. *TDS curves for breads 5-8. The x-axis show time (s) and the y-axis show frequency (%). Each line represent a different attribute.*

gradually. The sample was perceived as *sticky* in the end, starting at 75 seconds and until oral processing ended.

Bread 3

The TDS curve for bread 3 shows that attribute *chewy* was perceived during the first 10-25 seconds. The attribute *juicy* was significant throughout the oral processing, but varied in frequency. *Dough-like* was the most dominant attribute for the sample, and lasted for approximately 40 seconds. In the end, bread 3 was perceived as *sticky*. In comparison between samples, bread 3 was the sample where the attribute *dough-like* was perceived as dominant for most of the oral processing. This sample was selected for further testing.

Bread 4

Bread 4 was perceived as *dry* at the beginning of the oral processing, declining after 25 seconds. For approximately 50 seconds, some of the texture attributes were perceived as barely dominant (crumbly, coarse, and dry). After 75-80 seconds, the sample was perceived as *sticky* and *dough-like*, until attribute *juicy* peaked in the end.

Bread 5

The TDS curve for bread 5 shows that *chewy* was the most dominant attribute after 15 seconds, which lasted for 20 seconds. The sample was then perceived as *soft*, and then *juicy*, until attribute *sticky* peaked in the end. In comparison between samples, bread 5 was the most *chewy* and *sticky* bread. This sample was selected for further testing.

Bread 6

Bread 6 was perceived as *dry* for the first 40 seconds and as *crumbly* between 30 and 80 seconds. *Dry* and *crumbly* were the dominating attributes until the end of the oral processing, when the sample was perceived as *juicy* and *sticky*. This sample was selected for further testing.

Bread 7

According to the TDS curve, bread 7 was perceived as *dry* at first. *Coarse* was the dominant attribute after approximately 25 seconds, which lasted for 50 seconds. The sample was also perceived as *chewy* after 20 seconds, which lasted for 50 seconds. In the end, bread 7 was perceived as *sticky* and *juicy*. In comparison between samples, bread 7 was the only sample where the attribute *coarse* was perceived as the main dominant attribute. This sample was selected for further testing.

Bread 8

The TDS curve for bread 8 show that *dry* was the most dominant attribute after approximately 5 seconds, and then the attribute *crumbly* peaked approximately 35 seconds in. Attributes *crumbly* and *dry* were significant for most of the oral processing, and *sticky* and *juicy* were dominant in the end.

Comparison between samples

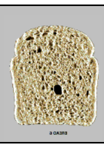
Breads 1, 4, 6, 7 and 8 had *dry* as the most dominant attribute in the beginning. Bread 3 stood out as the most *doughy* sample, and bread 5 was the most *chewy* and *sticky* sample. Bread 6 and 8 were the only samples perceived as *crumbly* (above significant level). However the attribute *crumbly* lasted longer for bread 6, and was more dominant for bread 8. Bread 7 was the only sample perceived as *coarse* (above significant level). All samples were perceived as *sticky* and *juicy* in the end of oral processing, as expected due to moistening of bread with saliva in order to prepare the bolus for swallowing.

Sample selection for further testing- based on TDS results and instrumental results

Based on the TDS curves four samples presenting different dynamic texture profiles were selected for further sensory analysis and for the consumer test on expected satiation and expected satiety. The selected samples were breads 3, 5, 6 and 7. Table 9 shows which attributes were dominant in the *start*, *middle* and *end* of oral processing, and which attributes that never were dominant.

Breads 3 and 5 were similar in the beginning of mastication and then bread 3 was perceived as *dough-like*, while bread 5 was *soft*. Breads 6 and 7 were both perceived as *dry* at first, and then bread 6 was *crumbly* while bread 7 was *coarse* and *chewy*. The instrumental analysis showed a significant difference in volume for breads 1-8 (section 6.1). The samples chosen for further analysis (breads 3, 5, 6 and 7) were all significantly different in volume, and similar in dough and slice weight. The bread firmness for the samples chosen for further analysis were all significantly different from each other, showing they represented the whole range of firmness among the eight breads.

Table 9. Bread selection based on TDS curves

	Curve	**Bread 3**	**Bread 5**	**Bread 6**	**Bread 7**
Dominant attributes	Start	Chewy	Chewy	Dry	Dry
	Middle	Dough-like Juicy	Soft Juicy	Crumbly	Coarse Chewy
	End	Sticky Juicy	Sticky	Sticky Juicy	Sticky Juicy
Not dominant attributes	Whole	Dry Coarse Crumbly	Dry Coarse Crumbly	Coarse Dough-like	Soft Dough-like
	Visual				

6.2.2 Quantitative Descriptive Analysis (QDA)

The trained panel conducted a QDA on the four selected samples (based on the TDS analysis). The spider plots (Figure 23) show the differences between samples. Differences especially occur in texture attributes (Figure 23a). However, breads 3 and 5 are quite similar in their texture profiles. Large differences across samples were expected in texture, but not in taste and flavor, as per product design. Data was analyzed in a 2-way ANOVA including factors product and assessor. Results of the ANOVA for product effect (from PanelCheck software) and a Tukey test showed significant differences between samples for all texture attributes (Figure 24). Breads 3 and 5 were not significantly different from each other for any of the attributes. They were the least *porous* and *crumbly*, and the most *sticky* and *doughy* samples. Bread 6 was significantly more *porous* than breads 3 and 5, but less *porous* than bread 7. For all other texture attributes, bread 6 was similar to one or two of the other samples and did not stand out. Breads 7 stands out the most for texture attributes, and is significantly more porous, hard, coarse and chewy than the other samples.

The most *sticky*, *doughy* and least *crumbly* breads (breads 3 and 5) were made with scalded barley flour (fine and coarse), and the most *crumbly*, least *sticky* and *doughy* breads (breads 6 and 7) were made with soaked barley flakes (thin and thick) (Table 2).

For flavor attributes, the samples were significantly different for the attributes *sour*, *sweet* and *salty* (Figure 25). Bread 6 was significantly more *salty* than breads 3, 5 and 7. When looking at the experimental design for the baking process (Table 2) there is no relation between flavor attributes and baking process parameters.

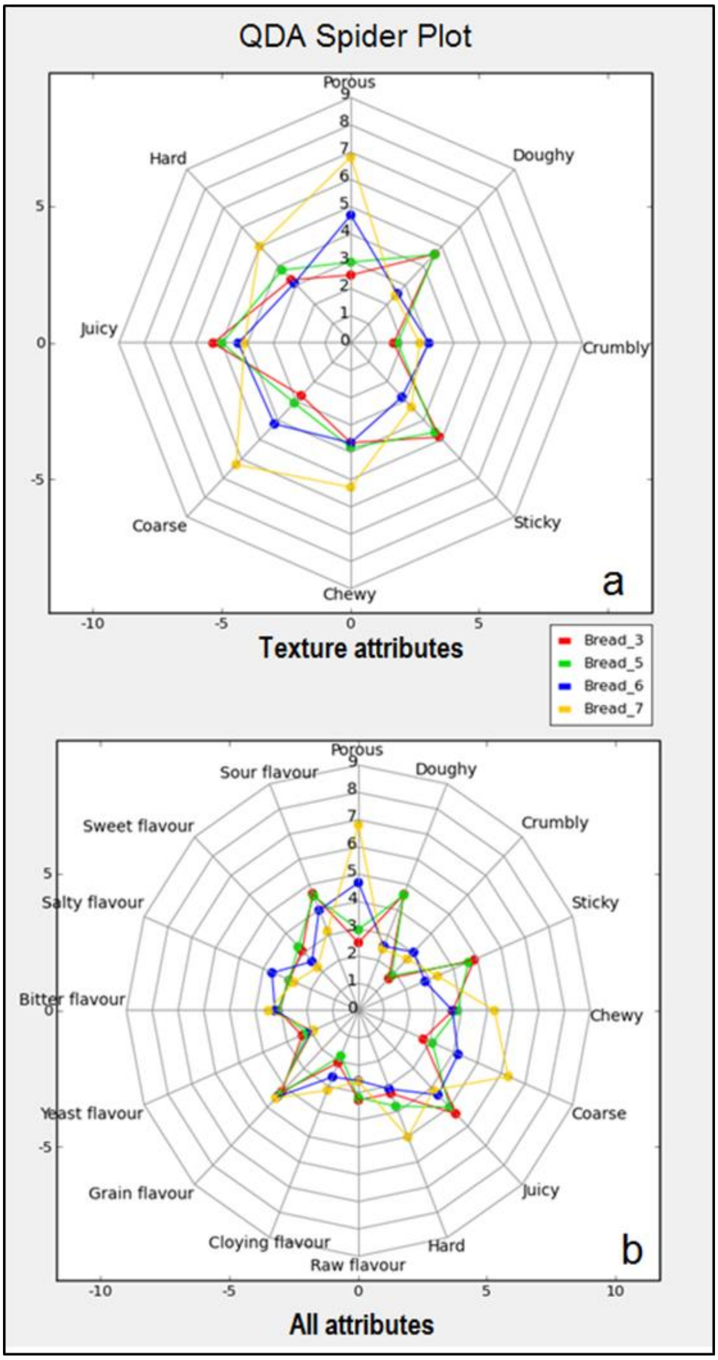


***Figure 23**. Spider plots of QDA results.*
***a)** Texture attributes **b)** All attributes.*

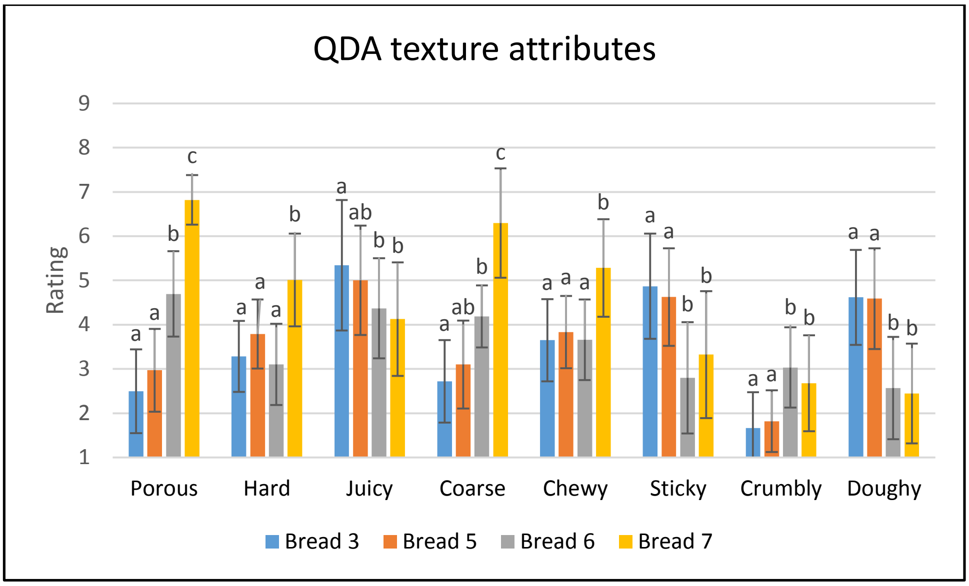


Figure 24. *Texture attributes, presented as mean ratings from 1-9. Means that do not share a letter are significantly different from the other samples.*

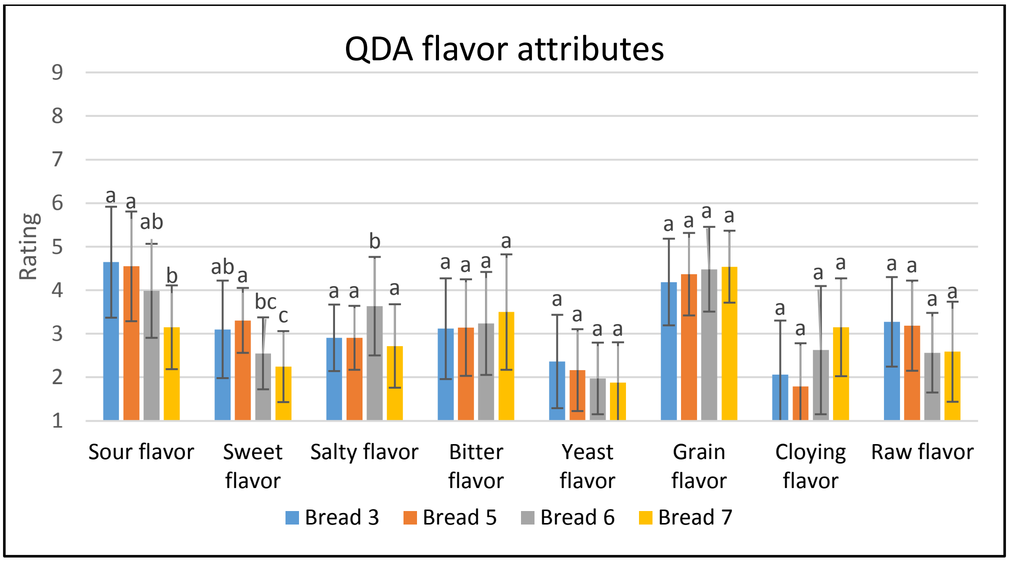


Figure 25*. Flavor attributes presented as mean ratings from 1-9. Means that do not share a letter are significantly different from the other samples.*

6.3 Consumer testing

In total, 96 consumers completed the consumer test, rating acceptance, expected satiation and expected satiety for breads 3, 5, 6 and 7, and provided product descriptions by completing a CATA task. Section 6.3.1-6.3.6 presents the results.

6.3.1 Consumer demographics and habits regarding bread consumption

The consumers were recruited as presented in section 5.4.1. Table 10 presents the demographics and habits concerning bread consumption for the 96 people who completed the consumer test. The consumer frequency of bread consumption was high, and as many as 81/94 reported to eat bread five days a week or more. One of the consumers reported eating bread 1-2 days a week, however, in the recruitment process consumers who did not consume bread 3-4 days a week or more were excluded. The reason why this consumer reported differently in the recruitment and in the test is unknown. The participants regularly consume bread for breakfast (86/96) and lunch (84/96).

Table 10. Consumer demographics and habits concerning bread consumption

Consumer sample (*n*=96)			
Gender		***Bread consumption (days/week)***	
Male	45	1-2 days	1
Female	51	3-4 days	14
		5-6 days	33
Age (years)	18-40	7 days	48
Mean	*24.9*		
BMI (kg/m³)	18.9-29.9		
Mean	*23,7*	***Bread regularly consumed for***	
		Breakfast	86
Education		Lunch	84
High school	32	Dinner	3
University/college (1-4 years)	50	Supper	60
University/college (5+ years)	14	Snack/ between meals	33
Currently			
Student	75		
Employed full time	17		
Employed part time	15		

6.3.2 Acceptance

The consumers rated hedonic acceptance of the four samples in randomized monadic presentation. ANOVA for acceptance did not show a significant difference between the four samples (figure 26). This indicated that consumers on average did not like any of the samples more than the others, and acceptance will therefore not have influenced the satiation and satiety ratings (Blundell et al. 2010).

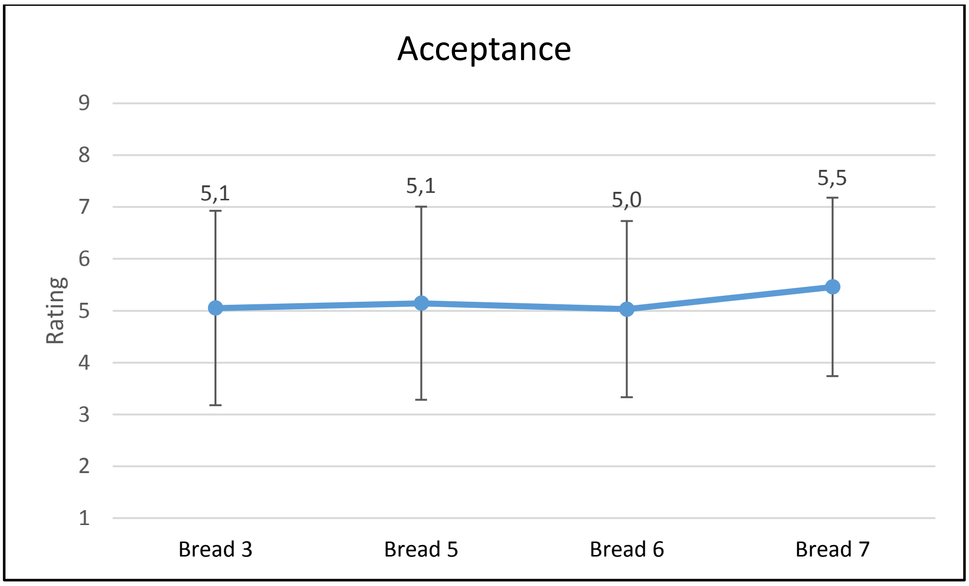


Figure 26. *Acceptance, rated from 1-9 for breads 3, 5, 6 and 7.*

6.3.3 Expected satiation and expected satiety

The participants consumed a small piece of each bread, and rated their expected satiety and expected satiation in a randomized monadic presentation. Looking at the mean values for expected satiation and expected satiety, the trends were similar (Figure 27 and 28).
ANOVA for expected satiation showed a significant difference between samples (Figure 27). A Tukey analysis on the results showed that bread 6 presented a significantly lower expected satiation than the other samples. Breads 3 and 5 had the same average rating for satiation (5.8 and 5.8). Bread 7 was expected to be more satiating than bread 6, and had lower ratings (however not significantly different at a 5% level) than breads 3 and 5.
For expected satiety ANOVA showed significant differences between products and Tukey analysis showed that bread 6 was different from the other samples (figure 28). As for expected satiation, bread 6 had lower ratings than the other breads for expected satiety.

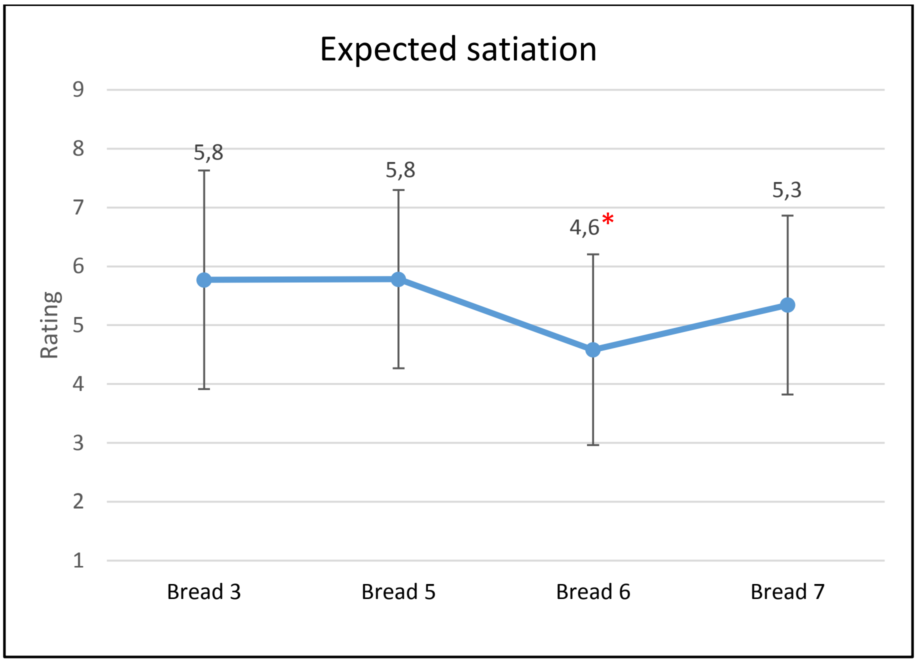


Figure 27. *Expected satiation for bread 3, 5, 6 and 7, rated from 1="Not full at all" to 9="Very full". *Sample is significantly different from the other breads.*

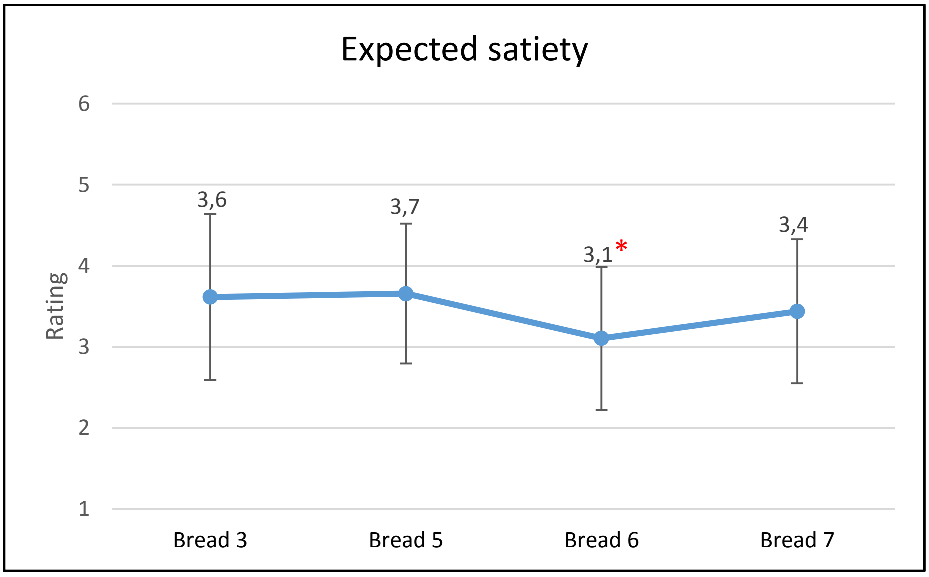


Figure 28. *Expected satiety for breads 3, 5, 6 and 7, rated from 1= "hungry again at once", to 6= "full for 5 hours or longer" *Sample is significantly different from the other breads.*

6.3.4 Current hunger level

Prior to testing the bread samples, consumers indicated their hunger level on a scale from 1= "Not hungry at all" to 9= "Very hungry". Consumer hunger ratings were separated into two groups: *low hunger level*, which includes those who rated from 1.0 to 5.0 (21/96 participants), and *high hunger level* for those who rated from 5.1 to 9.0 (75/96 participants).

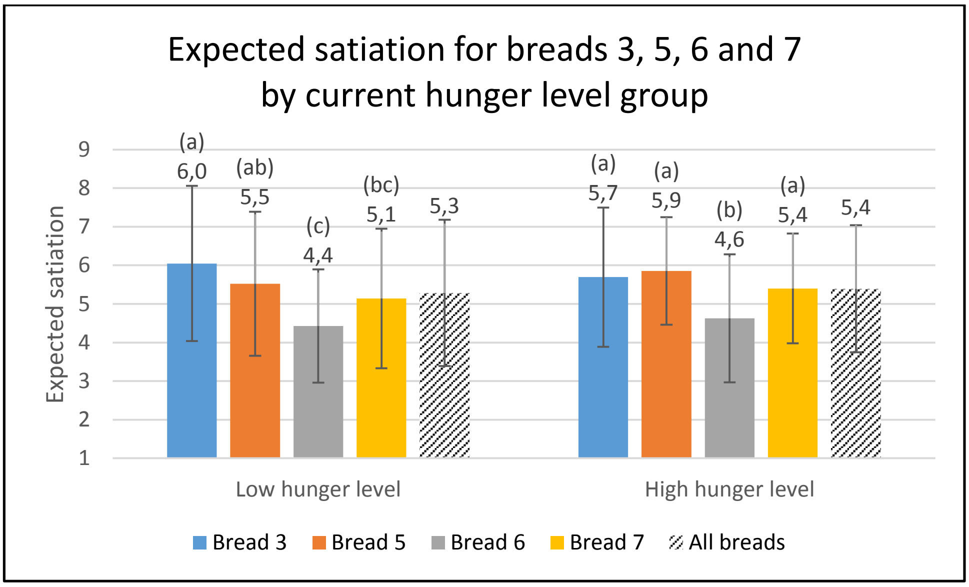


Figure 29*. Expected satiation (y-axis, presented as means) in relation to hunger level group (x-axis). Means that do not share a letter are significantly different from each other (within groups).*

Results showed consumers varied in current hunger level, from 1.9 to 9 on the scale (mean= 6.3). The satiation ratings for the two hunger level groups were analyzed by ANOVA and a Tukey test in order to compare expected satiation between groups. Results showed consumers who had low hunger levels when participating in the consumer test rated satiation differently from the hungry consumers. The significant differences in satiation between samples for participants with low hunger levels showed that bread 3 was rated as significantly more satiating than breads 6 and 7 and that bread 5 was only significantly different from bread 6. Results for the consumers with high hunger levels showed similar significant differences between breads as for the results on expected satiation (all consumers combined), where bread 6 was significantly different from breads 3, 5 and 7.

6.3.5 Check-all-that-apply (CATA)

The consumers conducted a Check-all-that-apply (CATA) description task for breads 3, 5, 6 and 7. A contingency table was built, displaying only significant attributes identified from Cochran's Q test with significance level 5% (Appendix 3). Figure 30 gives an overview of the CATA results for the four samples. The numbers represent how many times an attribute was checked by the consumers (n=96) for each sample. The letters between the brackets indicate which samples were significantly different from each other for each attribute. Attributes *compact*, *airy* and *medium coarse* were selected most frequently by the consumers. Breads 3 and 5 were described as *compact*, *doughy*, *heavy*, *medium coarse* and *sticky*. Bread 6 was described as *airy* and *medium/not coarse,* and bread 7 as *airy* and *medium coarse*. Bread 6 had the highest number of checks for the attribute not coarse, however it was not significantly different from bread 5. When comparing samples, breads 3 and 5 were more *compact*, *doughy* and *heavy*, and less *airy* and *porous* than breads 6 and 7.

The consumers also conducted the CATA description task on their ideal (imaginary) bread product. Correspondence Analysis (CA) was used to build a map displaying product profiles for the real samples and the ideal bread (Figure 31). Attributes placed next to the ideal in the plot indicates that the ideal bread should be *healthy*, *fibrous*, *very coarse, attractive*, *suitable for breakfast*, *lunch and the weekend, juicy*, *good*, *grainy flavored* and *satiating.* None of the breads in the experiment directly matched this mean ideal product, but bread 7 was the closest. The ideal bread should not be *dry*, *sour, crumbly, sticky, doughy, compact, heavy, hard*, *unhealthy*, or *yeast flavored*.

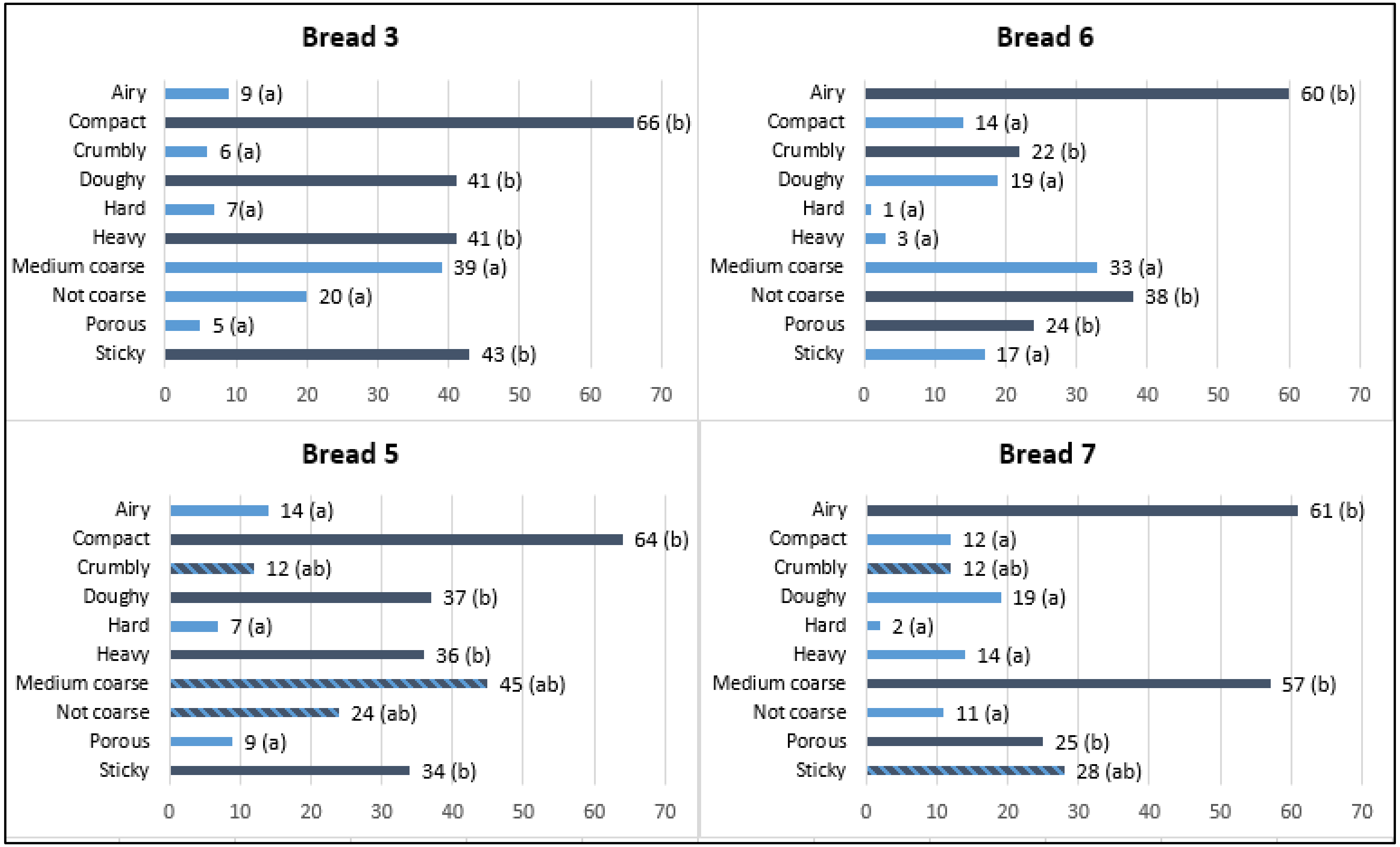


Figure 30 *CATA results. The bars represent the selection frequency of each attribute from the consumer evaluation of samples 3, 5, 6 and 7. Attributes with different letters (between brackets) were significantly different between samples. Light blue color represent (a), dark color (b) and striped (ab).*

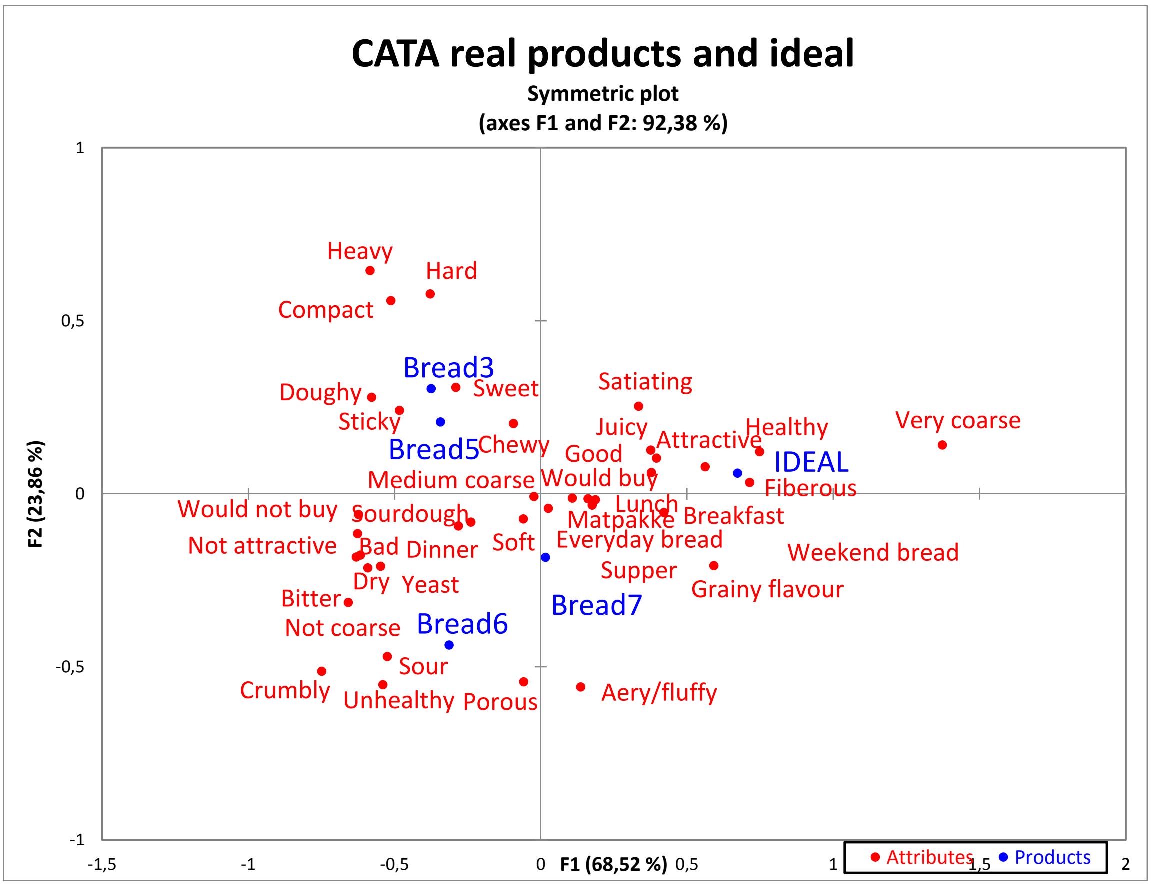


Figure 31. *CATA results from the real samples and the ideal.*

6.3.6 Statements regarding bread, health and satiation

The 96 consumers were asked how much they agreed or disagreed on four statements regarding bread, health and satiation. Figure 32 shows how the consumers rated the statements on a scale ranging between 1 and 9. For statement 1, "*When I buy/bake bread I think about how satiating the bread is*" the results show that the majority of the consumers rated between 7 and 9. This indicates that consumers are concerned about the satiating capacity when buying/baking bread. Statement 2 was; "*White bread is as healthy as coarse bread*". For this assertion, all of the consumers rated between 1 and 5, and as many as 83 of them rated 1, indicating the consumers disagreed on the statement. For statement 3, "*If I am going to get properly satiated, it is crucial that the bread is coarse*", most of the consumers rated between 6-9, indicating that consumers think bread needs to be coarse for them to get properly satiated. Statement 4 was "*When eating white bread, you need more slices to get satiated than if you eat coarse bread*" and 83/96 consumers rated their agreement between 7 and 9, indicating the majority agreed on the statement. Conclusively, the consumers thought coarse bread is healthier and more satiating than white bread and that satiating capacity is important.

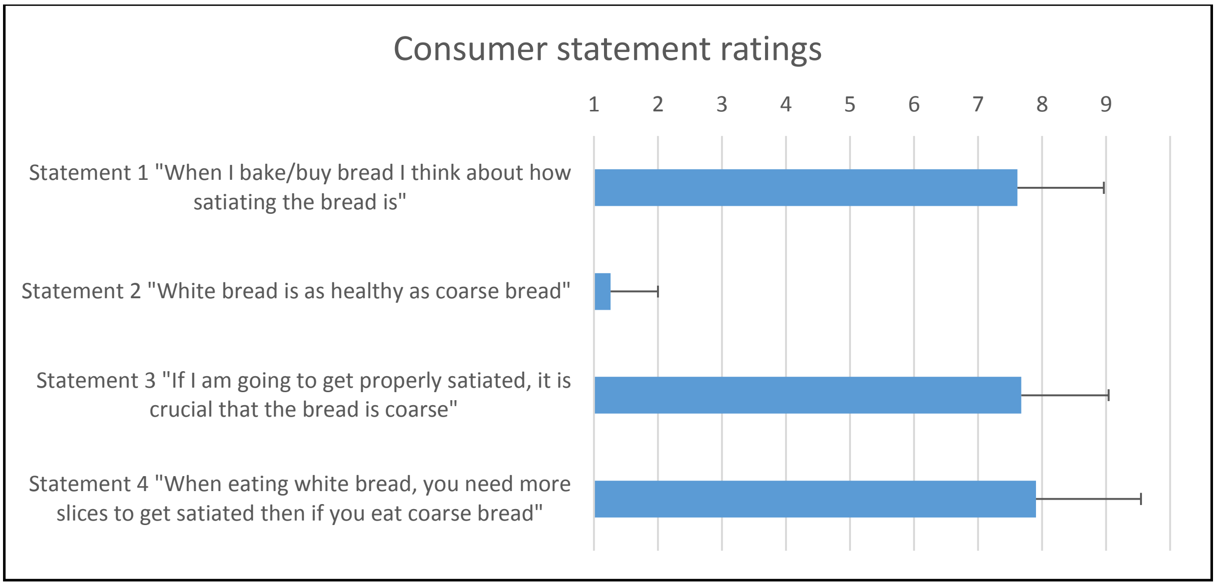
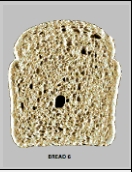


Figure 32. *Consumer ratings on statement 1-4 rated on a scale from 1-9.*

6.4 Overview of results

Table 11 shows an overview of breads 3, 5, 6 and 7 including results from instrumental analysis, QDA, TDS and the consumer test. Consumers expected breads 3, 5 and 7 to be more satiating than bread 6. Bread 3 was made with fine barley flour and was scalded and fermented, it was *small, firm, compact, doughy, juicy, sticky, heavy* and *medium coarse*. Bread 5 was made with coarse barley flour and was scalded and not fermented. This bread was very similar to bread 3, only *softer* and less *juicy* and *doughy*. Bread 6 was made with thin flakes and was soaked and fermented. The sample was *big, not firm, crumbly, airy* and *medium/not coarse*. According to both the TDS and the QDA, bread 6 was *not doughy*. Bread 7 was made with thick flakes and was soaked and not fermented. The sample was *medium firm, coarse, chewy, porous, hard, coarse* and *chewy*.

Table 11. Overview of bread properties, instrumental measures and sensory descriptions for the bread samples

		See section	Bread 3	Bread 5	Bread 6	Bread 7
						
Background measures	**Type and size of barey**	5.1.1	Fine flour	Coarse flour	Thin flakes	Thick flakes
	Treatment	5.1.1	Scalding	Scalding	Soaking	Soaking
	Fermentation	5.1.1	Yes	No	Yes	No
	Weight slices (g)	6.1	32.0 (ab)	30.4 (ab)	27.9 (ab)	28.2 (ab)
	Volume (cm^3)	6.1	1070.7 (e)	1164.8 (d)	1582.7 (a)	1280.2 (c)
	Moisture content (%)	6.1	48.5 (c)	48.8 (c)	50.1 (ab)	50.0 (ab)
	Visual description	6.1	Small Compact	Small	High	Coarse Airy
	Texture analyzer	6.1	Firm	Firm	Not firm	Medium firm
Trained panel	**TDS dominant attributes**	6.2.1	Dough-like Juicy Chewy	Soft Juicy Chewy	Crumbly Dry	Coarse Chewy Dry
	TDS attributes *not* dominant	6.2.1	Dry Coarse Crumbly	Dry Coarse Crumbly	Coarse Dough-like	Soft Dough-like
	TDS oral processing time (s)	6.2.1	27.2 (a)	27.2 (a)	31.4 (b)	31.3 (b)
	QDA texture attributes high intensity	6.2.2	Juicy Sticky Doughy	Juicy Sticky Doughy	Crumbly Porous Coarse	Porous Hard Coarse Chewy
	QDA texture attributes low intesity	6.2.2	Porous Coarse Crumbly	Porous Crumbly	Sticky Doughy	Sticky Doughy
	QDA flavor attributes	6.2.2	Sour Sweet	Sour Sweet	Salty Sour	-
Consumer test	**Expected satiation Expected satiety**	**6.3.3**	**High**	**High**	**Low**	**High**
	CATA profile (consumers)	6.3.5	Compact Doughy Heavy Medium coarse Sticky	Compact Doughy Heavy Medium coarse Sticky	Airy Medium coarse Not coarse	Airy Medium coarse

7. Discussion

The objective of the thesis is to understand the role of oral processing and texture in consumers' perception of satiety. In this chapter results are compared and discussed, focusing on the correlation between the sensory descriptions and product profiles, and consumers expected satiation and expected satiety for breads 3, 5, 6 and 7.

7.1 Sample selection

The breads chosen for consumer testing were based on the results from the instrumental analysis and the TDS. Breads 3, 5, 6 and 7 were all significantly different in volume, and similar in dough and slice weight. This indicates that the breads were comparable in terms of caloric content, and volume differences were caused by various amounts of air in the bread structure, leading to textural differences only. The bread firmness for the samples chosen for further analysis were all significantly different from each other, showing they represented a wide range of firmness among the eight breads. The results from instrumental analysis have been found in previous works to correlate well with sensory measures (Gámbaro et al. 2002). This seems to be the case for this study as well, as results from the Texture analyzer showed that all the firm samples were described as *chewy* (TDS), and the sample highest in volume was described as less *doughy* than samples smaller in volume. From the TDS results, breads 3, 5, 6 and 7 presented very different texture profiles. The objective of the thesis required samples different enough in texture, in order for consumers to be able to perceive differences between samples, but still similar in terms of composition and energy density; the sample characterization showed we succeeded in these regards.

7.2 Oral processing time

The results on oral processing time showed significant differences between samples 3, 5, 6 and 8. Samples expected to be the most satiating (breads 3 and 5) were the samples with the longest oral processing time. The results from the TDS, QDA and CATA task showed these samples were perceived as *compact*, *doughy*, *sticky* and *chewy*. Bread 6 was described as *airy*, *crumbly* and *porous.* This indicates a more *compact*, *doughy* and *sticky* bread takes longer to process, than an *airy, crumbly* and *porous* bread. Previous works showed that longer oral processing time might contribute to higher satiation within iso-caloric meals, and that oral processing time for the same amount of food can vary greatly, for example 27 seconds for 50 g of canned tomatoes and 350 seconds for 50 g of tortilla chips (Forde et al. 2013). The oral processing time for the bread samples might have affected the expected satiety ratings in this study as well. However, bread 6 had the shortest oral processing time and the least expected satiety, but was not significantly different from bread 7 in oral processing time (bread 7 was expected to be more satiating than bread 6). In the same lines, sample 7 had a significantly lower oral processing time than samples 3 and 5, but they did not present significant differences in expected satiety ratings. Previous studies suggested the link of satiety perception and harder or more viscous texture because of longer eating rates or longer oral exposure (Forde et al. 2013; Tárrega et al. 2014). However, the results of our work suggest that it is not only a question of hardness and eating rate, but also a more complex issue. The present study suggests there could be a relation between the dominance of the difference in texture perception during mastication and the perception of satiety, as samples with similar eating rates were rated differently on their perception of satiety (breads 6 and 7) and samples with different eating rates were perceived as equally satiating (breads 3, 5 and 7).

A number of factors might influence the food intake during an eating event, including sensory and cognitive factors, as explained in the Satiety cascade (Figure 2) by Blundell (2010). Many studies have shown longer duration of oral processing can lead to accelerated meal termination (Bolhuis et al. 2011; Ruijschop et al. 2011; Zijlstra et al. 2009), however other studies have shown the increase in volume of a product can, unrelated to oral processing time, affect expected satiety (Arboleya et al. 2014). This indicates that oral processing time alone is not the only factor in increased satiation due to oral processing, and that expectation of products filling effects could contribute to the amount of food eaten.

7.3 The use of both static and dynamic sensory methods

When looking at the results for the texture attributes, the TDS provided a detailed description of the oral processing, and the QDA provided information on the intensity for each attribute. When relating QDA to TDS results it is clear that there is a difference in static and dynamic sensory evaluations. Looking at QDA results on texture for example, bread 6 is described as a somehow average bread, but looking at the TDS results bread 6 was perceived as very different. Some attributes did not seem to differ between samples when looking at QDA results (for example the attribute *juicy*), but were very different in terms of dominance in the TDS. A combination of static (QDA) and dynamic (TDS) sensory methods seems to provide more valuable and detailed information on texture attributes, that might not have been identified if only one method was applied, as observed in other studies using both TDS and QDA (Ng et al. 2012).

7.4 Acceptance

The results for the consumers' acceptance showed no significant difference between samples, indicating consumers on average did not like any of the samples more than the others. Blundell et al. (2010) listed palatability as an important factor involved in meal termination in both controlled studies and more real-life studies. For this work, based on the acceptance ratings, the palatability factor will not have influenced the expected satiation and expected satiety ratings. These results are calculated based on mean ratings, and do not reflect the consumers' individual preferences for bread. When deciding on the recipe and the procedure for the baking, the focus was on varying texture and not flavor, therefore differences in texture were designed, while flavor was expected to be similar across samples, due to the usage of the same basic ingredients across recipes.

7.5 Measuring expected satiety and expected satiation

For expected satiety and expected satiation, breads 3, 5 and 7 were perceived to be more satiating than bread 6. Looking at the mean values for expected satiation and expected satiety, the trends were similar indicating there was not much difference in assessing satiation and satiety. This correlation between expected satiety and expected satiation has also been found in several other studies by Brunstrom and his colleagues (Brunstrom 2011). Satiation ratings might be more related to texture than satiety ratings, as the texture is perceived in the mouth, however, fibrous food might be more viscous in the gut and therefore lead to higher satiety after an eating event ends (de Graaf 2012; Mattes & Rothacker 2001; Slavin & Green 2007). Thus, actual satiety like expected satiety, could be influenced by a product's texture.

Consumers were asked to rate their current hunger level prior to sample evaluation, in order to have an idea of the "baseline" to compare the satiety results. The results showed similar rating patterns (with sample 6 as less satiating), however, for consumers with low hunger level (n=21) the significant differences in satiation between samples differed from those in the high hunger level group (n=75). These results show that hunger level influenced discrimination ability between samples in terms of satiety ratings. The results for the high hunger group were similar to the results for satiation for all consumers combined (n=96). The differences in the low hunger group showed that these consumers were more discriminative between products in terms of expected satiety than consumers with high hunger levels. Therefore, in studies measuring expected satiety, it might be wise making sure participants have low hunger levels in order to obtain better product discrimination. Nevertheless, being that the group of consumers with low hunger level is so small, it is difficult to generalize recommendations, and more studies would be needed in this sense.

7.6 Expected satiation and expected satiety as related to texture attributes

When looking at the TDS curves related to the results for expected satiation and expected satiety it is possible to compare which dynamic texture attributes might have contributed to a higher expectance in satiation and satiety. The TDS results showed texture during oral processing is not static and attributes evolve during mastication, where different attributes were dominant at different stages. This change in attributes corresponds to what Lenfant et al. (2009) found when studying the perception of oral food break down, where the most changes in dominant sensations occurred during the first half of the mastication and all boli were perceived as *sticky* in the end.

During oral processing, the satiating samples were significantly *chewier* and less *crumbly* than bread 6, indicating these texture attributes might have influenced the expectations on satiety. These breads were also the *firmer* samples. Bread firmness and chewiness indicate longer oral processing time, as more time probably would be required for oral food break down. In other studies on satiation, *harder* and *drier* samples (high-protein pies) have been perceived as more satiating (Marcano et al. 2015), where longer oral processing time was assumed to have caused the results. In other studies, *thickness* (dairy products) has been found to be positively correlated with expected satiation (Hogenkamp et al. 2011), as has the attribute very *creamy* (Morell et al. 2014), and *high viscosity* (milk based snacks) (Tárrega et al. 2014). The present study suggests that the sequence and dominance of texture attributes perceived during oral processing are of importance in satiety perception, especially those dominant in the beginning and middle of mastication. This is in accordance with what was suggested in the study by Morell et al. (2014) where the results for milkshakes with different hydrocolloids suggested consumers related satiety more with the food characteristics at the very start of consumption rather than with the loss of structure in mouth.

When assessing the results from the QDA in relation to expected satiation and expected satiety it is possible to compare which static sensory attributes might have contributed to a higher expectance in feeling of fullness. The results showed significant differences between samples for all texture attributes, as expected due to the design for sample manufacturing and the selection of samples. The most satiating samples (breads 3 and 5) were significantly more *sticky* and *doughy* than the least satiating sample (bread 6). Bread 7 was *coarser* and *chewier* than the least satiating sample, however it was also the most *porous* sample, which might be why it was not perceived as more satiating than breads 3 and 5.

When assessing the results from the CATA task in relation to expected satiation and expected satiety it is possible to compare if consumer profiles of the samples contributed to a higher expectance in satiety. The most satiating samples (breads 3 and 5) were significantly more *compact*, *doughy* and *heavy* than the least satiating sample (bread 6), and less *airy*. Bread 6 had the highest frequency of selection for attributes *not coarse* and *crumbly*, which are attributes related to an easier oral processing. A combination between attributes might have influenced the results on expected satiety and expected satiation. The results combined showed all satiating samples were described by several texture attributes which might require longer oral processing, like *compact*, *heavy*, *sticky*, *doughy* (breads 3 and 5) *chewy*, *hard* and *coarse* (bread 7). And the least satiating sample (bread 6) was described less by attributes related to satiating texture properties, and more to attributes related to an easier oral processing, like *crumby* and *airy*. QDA and CATA profiles were very much aligned in their main conclusions.

7.7 Expected satiation and expected satiety related to flavor attributes

The QDA results show little variance in flavor among samples, as expected due to the design for sample manufacturing. The only flavor attribute significantly different between the least and most satiating samples was *salty*, where the least satiating bread was the saltiest sample. In a study on bread, Panouillé et al. (2014) found that denser bread was perceived as being less salty. Bread 6 was the most *crumbly*, least *firm* sample indicating low density, which might explain why bread 6 was perceived as more *salty* that the other samples. From a satiation perspective, previous studies relating salt and satiety showed that high saltiness intensity decreases food intake (Bolhuis et al. 2011). Moreover, saltiness has been reported have positive association to chewiness, indicating an increase in expected satiety (Forde et al. 2013) which is the opposite of the findings in this study. It has to be pointed out that those studies measured actual satiety by ad libitum intake, in which saltiness could play a role by reducing intake because of sensory specific satiety. However, when measuring expected satiation or expected satiety it is more likely that texture would play the main role in the perception.

7.8 Familiarity

Familiarity has been reported to be associated with higher satiety expectations (Brunstrom 2011; Hogenkamp et al. 2011). In this study, consumers evaluated four samples of a type of product (bread) they consume frequently and therefore are familiar to. The samples were not from commercial bread and were very similar to each other as the same recipe was used. In addition the satiety questions were measured in an evoked context, where consumers were told to imagine eating the bread as in a normal bread eating event. On the basis of these terms, the issue of familiarity were not expected to influence results on expected satiation and expected satiety differently between samples.

7.9 Bread as a satiating product

Most of the consumers were frequent bread eaters, and usually consumed bread for breakfast and lunch (Table 10). The statements showed that consumers meant that coarse bread is healthier and more satiating than white bread, and that satiating capacity is important. The

CATA task showed consumers thought of their ideal bread as *healthy*, *fibrous*, *very coarse* and *satiating*. These habits and attitudes might be typical of the Norwegian population; however, this would vary across countries. In Norway, bread of enhanced satiety could be a key product when it comes to encouraging responsible food consumption.

7.10 Hormones

This study did not measure hunger and satiety hormone levels during oral processing, however, previous studies have shown that changes in satiety hormone levels might have been influenced by oral processing time (Galhardo et al. 2012; Kokkinos et al. 2010), thus, influencing satiety results. This is, however, probably a more relevant measure for studies on actual satiety.

7.11 Limitations and future research

Manufacturing of bread samples for the thesis was conducted on two occasions. Once to produce eight breads with different texture profiles (analyzed by TDS), and a second time to produce the four selected samples for QDA and the consumer test. In section 6, results from TDS, QDA and the consumer test were compared. In order for these results to be valid, it is important that the bread samples used did not differ between batches. When baking at two occasions there is a chance of differences in the samples across baking events. However, the two baking events were performed with this issue in mind, and doughs, loaves and slices were compared across events.

Further, according to Nofima's baker, the breads with added sourdough might not have been as different in texture as planned, this because of the small amount of sourdough added, and the short resting time of the sourdough loaves (personal communication). Also, the visual description of breads 1-8 (section 6.1) could have been analyzed by Nofima's trained panel for a more accurate description.

This study showed that hunger level influenced discrimination ability between samples, which is something that should be considered for future research on expected satiety. Further investigation of actual satiety on the four bread samples would be interesting, and may be important to better understand how texture properties affect the amount of food eaten.

Further, a penalty analysis could have been performed on the results from the CATA question if expected satiation, expected satiety and overall liking had been measured for the ideal bread, this would be interesting in a future study.

8. Conclusion

The objective of this Master thesis was to understand the role of texture and oral processing of bread in consumers' perception of satiety.

In this study, four bread samples with different texture profiles were analyzed using the sensory methods Temporal Dominance of sensations (TDS) and Quantitative Descriptive Analysis (QDA). In addition, a consumer test was conducted where participants rated their expected satiation and expected satiety for the four breads, and provided product profiles answering to a Check-all-that-apply (CATA) question.

The results from the TDS showed texture during oral processing is not static and attributes evolved during mastication, where different attributes were dominant at different stages. The most satiating samples were all perceived as *chewy*, and the least satiating sample as *crumbly* during oral processing. These texture attributes caused changes in oral processing time, which has been shown to influence satiety. However, the oral processing time of the least satiating bread did not differ from the samples presented with higher satiating ratings, indicating that oral processing time is not the only factor influencing expected satiety. The QDA and CATA results showed that texture attributes related to a more demanding processing before the bolus is ready to swallow seemed to describe the most satiating breads, like attributes *compact*, *firm*, *doughy*, *juicy*, *chewy* and *coarse*. The least satiating sample was described as *crumbly* and *not firm*, indicating less effort would be required before swallowing the bolus.

Many factors might influence the food intake during an eating event and from this study, it is clear that texture during oral processing is a contributing factor, and that the sequence and dominance of texture attributes perceived during oral processing are of importance in satiety perception.

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APPENDIX 1

Consumer test questionnaire

Spørreskjema brukt ved forbrukertest, februar 2015

*(Forbrukerne svarte på skjemaet i EyeQuestion på PC, hver nye side de fikk på skjermen er merket med *** i dette vedlegget.)*

Velkommen til forbrukertest på brød!

****

Hvor sulten føler du deg akkurat nå?

****

I denne testen skal du vurdere totalt fire typer brød.

Hver prøve du får utlevert er merket med en tresifret kode. Det er viktig at du sjekker at den prøven du vurderer har samme kode som du får opp på skjermen.

Hvis det er noe du lurer på er det bare å rekke opp hånden, så hjelper vi deg.

Lykke til!

***

(De neste spørsmålene var designspørsmål, og ble gjentatt for hver prøve)

Kode xxx

Vennligst spis opp <u>en</u> av brødbitene du har fått utdelt for denne koden.

Du skal så klikke på neste, og svare på noen spørsmål.

***

Kode xxx

Hvor godt liker du dette brødet?

Liker ikke i det hele tatt				Verken liker eller misliker				Liker veldig godt
○	○	○	○	○	○	○	○	○

***

Kode xxx

Tenk deg at du hadde spist et vanlig brødmåltid med dette brødet, med samme type pålegg og samme antall skiver som du vanligvis spiser.

Hvor mett tror du at du hadde blitt av dette brødet?

Ikke mett i det hele tatt								Veldig mett
○	○	○	○	○	○	○	○	○

Hvor lenge tror du du ville holdt deg mett av dette brødet?

Sulten igjen med en gang	Mett opp mot 1 time	Mett opp mot 2 timer	Mett opp mot 3 timer	Mett opp mot 4 timer	Mett 5 timer eller lengre
○	○	○	○	○	○

***

Kode xxx

Du skal nå vurdere hvilke egenskaper du synes passer for dette brødet.

***

Kode xxx

Vennligst spis opp den siste biten samtidig som du vurderer hvilke egenskaper du synes beskriver brødet.

Kryss av for alle egenskapene du mener gjelder.

☐ Smak av surdeig	☐ Sur smak	☐ Myk
☐ Bitter smak	☐ Smak av korn	☐ Søt smak
☐ God smak	☐ Luftig	☐ Mye tyggemotstand
☐ Lite grovt	☐ Mellomgrovt	☐ Smulete
☐ Tungt	☐ Porøst	☐ Hardt
☐ Deigete	☐ Saftig	☐ Gjærsmak
☐ Dårlig smak	☐ Klebrig	☐ Veldig grovt
☐ Tørr	☐ Kompakt	
☐ Usunt	☐ Passer til lunsj	☐ Mettende
☐ Dette ville jeg ikke kjøpt	☐ Brød til helgen	☐ Passer til matpakke
☐ Passer til frokost	☐ Fiberrikt	☐ Passer til kveldsmat
☐ Ikke tiltalende	☐ Sunt/mye næring	☐ Hverdagsbrød
☐ Passer til middag (f.eks suppe)	☐ Tiltalende	☐ Dette ville jeg kjøpt

(Slutt på designspørsmål)

***

Vi vil nå at du skal tenke deg ditt ideelle brød.

Velg de viktigste egenskapene som du synes beskriver ditt ideelle brød.

- ☐ Smak av surdeig
- ☐ Bitter smak
- ☐ God smak
- ☐ Lite grovt
- ☐ Tungt
- ☐ Deigete
- ☐ Dårlig smak
- ☐ Tørr
- ☐ Sur smak
- ☐ Smak av korn
- ☐ Luftig
- ☐ Mellomgrovt
- ☐ Porøst
- ☐ Saftig
- ☐ Klebrig
- ☐ Kompakt
- ☐ Myk
- ☐ Søt smak
- ☐ Mye tyggemotstand
- ☐ Smulete
- ☐ Hardt
- ☐ Gjærsmak
- ☐ Veldig grovt

- ☐ Usunt
- ☐ Dette ville jeg ikke kjøpt
- ☐ Passer til frokost
- ☐ Ikke tiltalende
- ☐ Passer til middag (f.eks suppe)
- ☐ Passer til lunsj
- ☐ Brød til helgen
- ☐ Fiberrikt
- ☐ Sunt/mye næring
- ☐ Tiltalende
- ☐ Mettende
- ☐ Passer til matpakke
- ☐ Passer til kveldsmat
- ☐ Hverdagsbrød
- ☐ Dette ville jeg kjøpt

Andre egenskaper/kommentarer:

____

____

***

APPENDIX 1

Hvor enig/uenig er du i disse påstandene?

Når jeg kjøper/baker brød tenker jeg på at brødet må være mettende.

Helt uenig				Verken enig/uening				Helt enig
○	○	○	○	○	○	○	○	○

Loff er like sunt som grovt brød.

Helt uenig					Verken enig/uenig				Helt enig
○		○	○	○	○	○	○	○	○

At brødet er grovt er avgjørende for at jeg skal bli ordentlig mett.

Helt uenig				Verken enig/uenig				Helt enig
○	○	○	○	○	○	○	○	○

Når man spiser loff trenger man flere skiver for å bli mett enn hvis man spiser grovt brød.

Helt uenig				Verken enig/uenig				Helt enig
○	○	○	○	○	○	○	○	○

***

Helt til slutt ønsker vi å vite litt mer om deg. Opplysningene du oppgir er anonyme.

Kjønn:

- ○ Kvinne
- ○ Mann

Alder:

Høyde:

Vekt:

Hva er din høyeste fullførte skoleutdanning?

- ○ Barne- og ungdomsskole
- ○ Videregående skole
- ○ Høyskole/universitet (1- 4 1/2 år)
- ○ Høyskole/universitet (5 år eller mer)
- ○ Ingen av disse

Er du?

Fulltidsstudent	Deltidsstudent	Arbeidstaker heltid	Arbeidstaker deltid	Annet
☐	☐	☐	☐	☐

Hvor mange dager i uken spiser du brød?

○ 7 dager i uken
○ 5-6 dager i uken
○ 3-4 dager i uken
○ 1-2 dager i uken

Til hvilket måltid spiser du vanligvis brød? (Flere valg mulig)

Frokost	Lunsj	Middag	Kveldsmat	Mellommåltid
☐	☐	☐	☐	☐

***

Du er ferdig med alle spørsmålene. Trykk send inn for å avslutte.

Du kan nå stille og rolig forlate plassen din. Vær vennlig å ta hensyn til de som ikke er ferdige enda.

Takk for deltakelsen!

APPENDIX 2

Attribute list for QDA and TDS

BEDØMMELSE AV BRØD
Egenskapsforklaring

SMAK

Sursmak	Relateres til grunnsmaken sur Ingen intensitet = ingen syrligsmak Tydelig intensitet = tydelig syrligsmak
Søtsmak	Relateres til grunnsmaken søt (sukker / sukrose) Ingen intensitet = ingen søtsmak Tydelig intensitet = tydelig søtsmak
Saltsmak	Relateres til grunnsmaken salt (NaCl) Ingen intensitet = ingen saltsmak Tydelig intensitet = tydelig saltsmak
Bittersmak	Relateres til grunnsmaken bitter (kinin / koffein) Ingen intensitet = ingen bittersmak Tydelig intensitet = tydelig bittersmak
Gjærsmak	Smak av gjær Ingen intensitet = ingen gjærsmak Tydelig intensitet = tydelig gjærsmak
Kornsmak	Relateres til en smak av korn; hvete, rug, havre, bygg Ingen intensitet = ingen kornsmak Tydelig intensitet = tydelig kornsmak
Emmensmak	En flau / lite aromatisk smak Ingen intensitet = ingen emmensmak Tydelig intensitet = tydelig emmensmak
Råsmak	Relateres til en råsmak (lite stekt) Ingen intensitet = ingen råsmak Tydelig intensitet = tydelig råsmak

TEKSTUR

Hardhet	Mekanisk teksturegenskap relatert til kraften som må til for å bite gjennom prøven med jekslene Ingen intensitet = ingen hardhet Tydelig intensitet = tydelig hardhet
Saftighet	Overflateteksturell egenskap som beskriver væske absorbert eller avgitt fra et produkt. Munnfølelse av saftighet. Ingen intensitet = ingen saftighet Tydelig intensitet = tydelig saftighet
Grovhet	Teksturegenskap knyttet til munnfornemmelse av partikkelstørrelse og form i et produkt Ingen intensitet = ingen grovhet Tydelig intensitet = tydelig grovhet
Tyggemotstand	Mekanisk tekstur egenskap relatert til tid og antall tygginger som er nødvendig for å finfordele prøven klar for svelging Ingen intensitet = ingen tyggemotstand (mør) Tydelig intensitet = tydelig tyggemotstand (seig)
Klistrighet	Mekanisk teksturegenskap relatert til kraften som skal til for å fjerne et stoff som kleber seg fast i munnen eller til et underlag Ingen intensitet = ingen klistrighet Tydelig intensitet = tydelig klistrighet
Smuldret	Mekanisk teksturegenskap som beskriver den nødvendige kraft som skal til for å bryte et produkt til smuler eller biter. Ingen intensitet= ingen smuldring Tydelig intensitet= tydelig smuldret
Deigete	Mekanisk strukturell egenskap relater til den anstrengelse som skal til for å finfordele produktet til en tilstand klar for svelging, relatert til et moderat nivå av seighet. Ingen intensitet= ikke deigete Tydelig intensitet= tydelig deigete

APPENDIX 2

Porøsitet	Hulrom / kanaler i krummen, refererer til Dahlmans porøsitetstabell Ingen intensitet = liten poring Tydelig intensitet = tydelig poring
Tørrhet	Overflateteksturell egenskap som beskrifter oppfatningen av vann absorbert av eller avgitt av et produkt, relatert til fuktighet Ingen intensitet= ingen tørrhet Tydelig intensitet= tydelig tørrhet
Myk	Mekanisk teksturegenskap relatert til kraften som trengs for å oppnå en gitt deformasjon eller gjennomtregning av et produkt Ingen intensitet= ingen mykhet Tydelig intensitet= tydelig mykhet

APPENDIX 3

Bread sample description by the consumers (CATA task)

Attributes showing the same letter between brackets are not significantly different (values from Cochran's Q test).

Attributes	p-values	Bread3	Bread5	Bread6	Bread7
Compact	0,000	0,688 (b)	0,667 (b)	0,146 (a)	0,167 (a)
Aery/fluffy	0,000	0,094 (a)	0,146 (a)	0,625 (b)	0,635 (b)
Grainy flavour	0,000	0,073 (a)	0,063 (a)	0,146 (a)	0,469 (b)
Heavy	0,000	0,427 (b)	0,375 (b)	0,031 (a)	0,146 (a)
Unhealthy	0,000	0,083 (a)	0,083 (a)	0,208 (b)	0,010 (a)
Porous	0,000	0,052 (a)	0,094 (a)	0,250 (b)	0,260 (b)
Fiberous	0,000	0,104 (a)	0,083 (a)	0,063 (a)	0,281 (b)
Not coarse	0,000	0,208 (a)	0,250 (ab)	0,396 (b)	0,115 (a)
Doughy	0,000	0,427 (b)	0,385 (b)	0,198 (a)	0,198 (a)
Sticky	0,000	0,448 (b)	0,354 (b)	0,177 (a)	0,292 (ab)
Satiating	0,001	0,375 (b)	0,313 (b)	0,135 (a)	0,250 (ab)
Medium coarse	0,002	0,406 (a)	0,469 (ab)	0,344 (a)	0,594 (b)
Crumbly	0,004	0,063 (a)	0,125 (ab)	0,229 (b)	0,125 (ab)
Sweet	0,004	0,240 (b)	0,167 (ab)	0,094 (a)	0,094 (a)
Sour	0,007	0,115 (ab)	0,073 (a)	0,219 (b)	0,104 (ab)
Would buy	0,008	0,156 (ab)	0,229 (ab)	0,125 (a)	0,292 (b)
Matpakke	0,022	0,323 (a)	0,406 (a)	0,323 (a)	0,479 (a)
Hard	0,042	0,073 (a)	0,073 (a)	0,010 (a)	0,021 (a)
Healthy	0,051	0,125 (ab)	0,135 (ab)	0,083 (a)	0,198 (b)
Dry	0,065	0,292 (a)	0,333 (a)	0,396 (a)	0,229 (a)
Chewy	0,066	0,229 (a)	0,229 (a)	0,104 (a)	0,188 (a)
Soft	0,120	0,375 (a)	0,365 (a)	0,458 (a)	0,313 (a)
Would not buy	0,130	0,438 (a)	0,333 (a)	0,385 (a)	0,302 (a)
Lunch	0,221	0,260 (a)	0,323 (a)	0,302 (a)	0,375 (a)
Bitter	0,293	0,063 (a)	0,063 (a)	0,094 (a)	0,031 (a)
Breakfast	0,345	0,333 (a)	0,323 (a)	0,323 (a)	0,417 (a)
Juicy	0,436	0,292 (a)	0,271 (a)	0,198 (a)	0,260 (a)
Good	0,503	0,302 (a)	0,271 (a)	0,219 (a)	0,292 (a)
Everyday bread	0,506	0,406 (a)	0,490 (a)	0,479 (a)	0,469 (a)
Supper	0,529	0,208 (a)	0,281 (a)	0,260 (a)	0,260 (a)
Not attractive	0,564	0,208 (a)	0,229 (a)	0,240 (a)	0,167 (a)
Very coarse	0,572	0 (a)	0,010 (a)	0,021 (a)	0,010 (a)
Bad	0,654	0,073 (a)	0,094 (a)	0,104 (a)	0,063 (a)
Weekend bread	0,691	0,083 (a)	0,073 (a)	0,115 (a)	0,104 (a)
Dinner	0,701	0,427 (a)	0,427 (a)	0,438 (a)	0,490 (a)
Yeast	0,792	0,104 (a)	0,125 (a)	0,146 (a)	0,115 (a)
Sourdough	0,806	0,146 (a)	0,115 (a)	0,135 (a)	0,156 (a)
Attractive	0,845	0,146 (a)	0,115 (a)	0,125 (a)	0,146 (a)

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