Effect of bleached oat hulls on physical and sensorial bread properties

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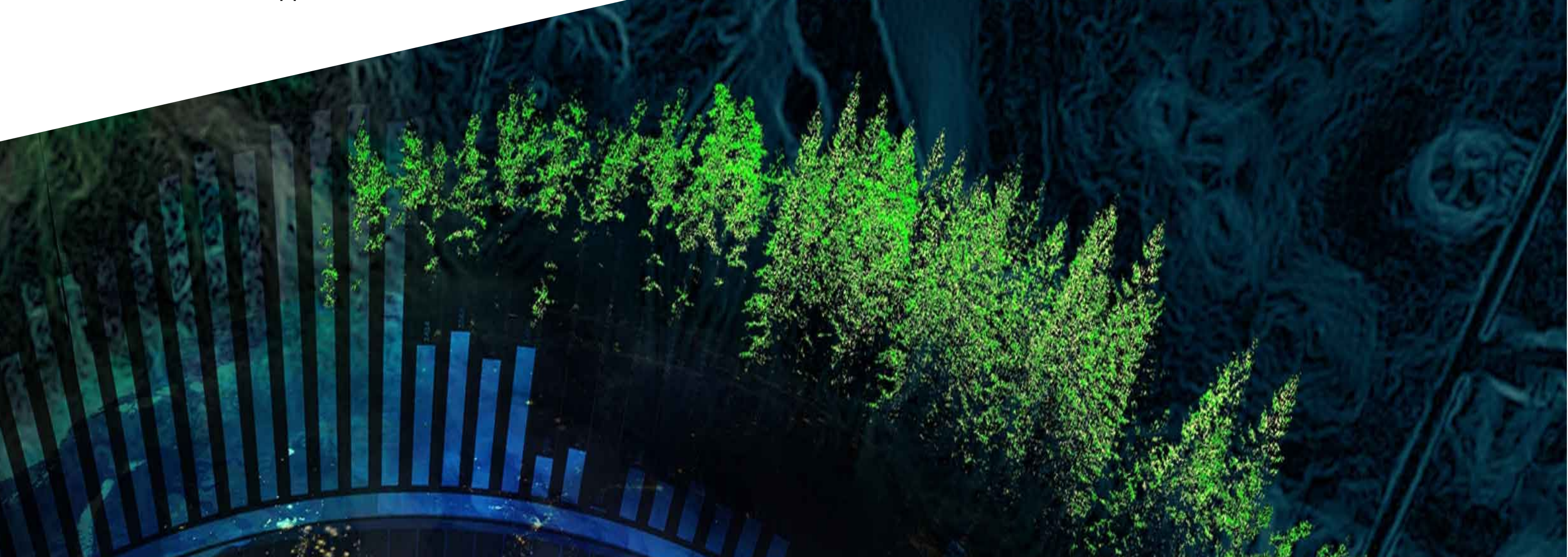

Effect of bleached oat hulls on physical and sensorial bread properties

Blekta havreskals effekt på bröds fysikaliska och sensoriska egenskaper

Carolin Marklund

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Abstract

The fight against today's environmental challenges must be present in all industries, including the food industry. One contributing element could be to take care of the side streams that occur in food production. Oat hulls are a side stream from oat production. They contain mainly fibre (85%), which could have a beneficial impact on human's health. Bread is a popular food and a suitable product for adding fibre. In this project, bleached oat hulls were milled into two different flours with different particle size. Bread was baked with the different oat hull flours or a reference fibre, at three different addition levels. Physical analyses were performed on the breads. No significant difference between the breads was found for specific volume. The bread baked with oat hulls had more yellow colour while the bread baked with reference fibre was lighter in colour. The hardest bread was the bread baked with reference fibre. In terms of crumb structure, there was no significant difference in average cell size. In addition, a sensory analysis (triangle taste test) was performed, which showed no significant difference between the bread baked with oat hulls and the bread baked with reference fibre. Also, no significant difference could be detected between the bread baked with oat hulls and a control bread. Thus, the effect of bleached oat hulls on bread properties was not physically remarkable and not sensorially detectable, making them excellent candidates as a fibre additive in bread. Further research should focus on investigating the effects of bleached oat hulls on bread properties at a higher additional level.

Keywords: oat, oat hull, dietary fibre, milling, bread baking, bread properties

Sammanfattning

Kampen mot de nuvarande miljöutmaningarna är en stor utmaning för alla branscher, även livsmedelsindustrin. En bidragande faktor kan vara att ta hand om de sidoströmmar som uppstår i livsmedelsproduktionen. Havreskal är en sidoström från havreproduktion. De innehåller huvudsakligen kostfiber (85%), vilka kan ha en positiv inverkan på människors hälsa. Bröd är ett populärt livsmedel och en lämplig produkt för att tillsätta fibrer. I det här projektet maldes blekta havreskal till två olika mjölsorter med olika partikelstorlek. Bröd bakades med de olika havreskalsmjölerna eller med referensfiber (havrefiber), vid tre olika tillsatsnivåer. Fysiska analyser utfördes på bröden. Ingen signifikant skillnad mellan bröden hittades för specifik volym. Brödet bakat med havreskal hade en gulare färg medan brödet bakat med referensfiber hade en ljusare färg. Det hårdaste brödet var det som var bakat med referensfiber. När det gäller strukturen av inkråmet fanns det ingen signifikant skillnad i genomsnittlig cellstorlek. Dessutom utfördes en sensorisk analys (triangeltest) som inte visade någon signifikant skillnad mellan brödet bakat med havreskal och brödet bakat med referensfiber. Ingen signifikant skillnad kunde heller påvisas mellan brödet bakat med havreskal och ett kontroll-bröd. Effekten av blekta havreskal på brödets egenskaper var således inte betydande vad gäller de fysikaliska egenskaperna och inte sensoriskt detekterbar, vilket gör dem till utmärkta kandidater som fibertillsats i bröd. Ytterligare forskning bör fokusera på att undersöka effekterna av blekta havreskal på brödegenskaper på en högre nivå av tillsatt fiber.

Sökord: havre, havreskal, kostfiber, malning, brödbakning, brödegenskaper

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Abbreviations

ANOVA	Analysis of variance
BU	Brabender units
DF	Dietary fibre
IDF	Insoluble dietary fibre
OHC	Coarsely milled bleached oat hulls
OHF	Finely milled bleached oat hulls
RF	Reference fibre
SDF	Soluble dietary fibre
SLU	Swedish University of Agricultural Sciences
TPA	Texture profile analysis
WHC	Water holding capacity

1. Introduction

In a world facing enormous environmental challenges, it is of the utmost importance to use all possible ways to achieve improvements (World Health Organization 2024). All industries have a responsibility to do their part, including the food industry. The food industry accounts for one third of the global greenhouse gas emissions (United Nations 2024). As major greenhouse gas contributors, it is crucial for the food industry to set climate targets and verify their carbon footprint (Liu et al. 2023). In order to reach those targets, changes need to be made in all parts of the food chain. One way could be to make food systems more resource-efficient and utilise by-products from production. Some of these by-products can be recovered and used for more than biogas or incineration (Ravindran et al. 2016).

In Sweden, 409 000 tonnes of oats were harvested in 2023 (Jordbruksverket 2023a). Oat hulls are a side stream from the oat industry. The hulls make up about 30% of the whole oat grain (Mares 2020). Currently, oat hulls are mostly used for incineration (Ravindran et al. 2016). Some innovation projects have been carried out to use oat hulls in the production of furniture and as an ingredient in cement (Mares 2020 & Klint 2023). Adding oat hulls to food products for human consumption is, if possible, even more exciting due to its high fibre content. Oat hulls have not yet been used in any food product. One challenge with adding oat hulls to food is that it results in a darker colour of the product. White fibres are mostly used as fibre supplement in food since they do not change the colour of the end-product. Therefore, to improve consumer acceptance of oat hulls in food, adjustments need to be made, which can be done by bleaching (Schmitz 2022). Bleaching not only improves the colour and thus consumer acceptance, but also raises the quality of the product. Bleaching removes unwanted flavours and odours, and some bleaching methods can improve the swelling capacity of the fibres by changing their functional properties (Abdel-Aal 2001).

Dietary fibre (DF) is necessary for a normal intestinal function and is an essential part of a healthy diet (Livsmedelsverket 2023). The fibre's ability to increase the sense of satiety reduces snacking and can additionally act as prebiotics (Isken et al. 2010). According to the Swedish Food Agency, Swedes need to increase their intake of dietary fibre (Livsmedelsverket 2023). In fact, the Swedish Food Agency and the Swedish Public Health Authority recently proposed several national targets, one of which is to increase the intake of dietary fibre with 100% by year 2035 compared to 2010 (Folkhälsomyndigheten 2024).

Oat hulls are extremely rich in fibre compared to other grain hulls (Ravindran et al. 2016). They consist of up to 83% lignocellulose, which is a material with three main components: cellulose, hemicellulose and lignin. The hemicellulose arabinoxylan accounts for 35% of the DFs in oat hulls. Cereal hemicellulose is of high interest to use as fibre supplement. Compared to wheat straw, the amount of hemicellulose is higher in oat hulls, making it a superior candidate for the purpose (Schmitz 2022).

Baking bread is an ancient and common way of processing grain. The shape of bread and the culture around it is different in different countries, but the ingredients are usually the same (Gould 2007). Since most people eat some form of bread on a regular basis, adding fibre to bread is a convenient way to increase the daily intake of dietary fibre and in line with the Swedish Food Agency's dietary advice (Livsmedelsverket 2024). Using oat hulls as a fibre additive in bread would thus not only reduce the side stream from oat production. It would also increase the nutritional value of bread and thus contribute to improving human health.

1.1 Purpose and aim

The aim of this project was to investigate the possibility of using bleached oat hulls as an additive in bread and investigate its effects on the properties of the bread. This was done by baking bread with three different addition levels of added bleached oat hulls, as well as two different oat hull flours with different particle sizes. The breads were analysed, both physically and sensorially, and compared with breads baked with reference fibre as well as a control bread without any added fibre.

2. Background

2.1 Bread baking

The first bread was made about 12,000 years ago (Mondal et al. 2008). Bread baking is thus an ancient way of transforming cereal flour and water into an edible product. Bread is eaten all over the world, although the processing methods and shapes differ. Thus, all parts of the world have their traditions and ways of preparing this popular, multifaceted food (Gould, 2007). The main ingredients of bread are flour and water, as they provide texture and crumb to the bread (Zanoni et al.1993). Other important ingredients are yeast, sugar, and salt. *Saccharomyces cerevisiae* (baker's yeast) is responsible for fermentation. Natural or added enzymes release sugars from starch. These sugars then act as nutrients for the yeast, which converts the sugar into CO_2 and moisture (H_2O). Salt strengthens the gluten network and helps to control the expansion of the dough. Fat can be added to increase processability and flavour (Giannou et al. 2003). Both protein denaturation and starch gelatinisation affect water diffusion in bread, by releasing and absorbing water when the temperature is between 60 and 85°C. This is one of the reasons why dough is transformed into bread (Mondal et al. 2008). The bread flavour is enhanced by a golden crust. The crust is formed mainly due to a Maillard effect that occurs when the bread is baked in the oven. This happens when the temperature rises 110 °C. The crust also contributes to a desirable surface colour, which plays an important role in consumer liking, along with texture and aroma (Zanoni et al. 1995).

2.2 Oats

Oat has been grown all over the world for thousands of years. Around the world, it is mainly grown for animal feed (70%), forage and bedding, but also for human consumption (20%), and industrial use (5%) (Hareland et al. 2003). In Sweden, oats account for about 15% of the total area of cereal production (Jordbruksverket

2023b). Oat is not as costly to produce as other crops and is often used as an alternative crop to avoid insects and crop diseases (Hareland et al. 2003). It is an adaptable crop that is resilient to cold, moist climates (Menon et al. 2016). Oat is an annual grass belonging to the grass family *Poaceae*, together with wheat, barley and rye (Prasadi et al. 2020). It is categorised under the genus *Avena,* a Latin word with origins meaning "nourishment" and "to desire". This is very true, as oats have been shown to provide health benefits to the consumer. For example, oats are known to reduce the risk of cardiovascular disease and type 2 diabetes, mainly due to the high content of the dietary fibre β-glucan (Menon et al. 2016). The link between β-glucan and a healthy gut microbiota is also an interesting topic but requires more research. However, the role of dietary fibre as a prebiotic is already well known (Prasadi et al. 2020, Slavin 2013).

2.2.1 Oat hulls

The hull makes up about one third of the weight of the oat grain (Hareland et al. 2003). In the processing of oats, dehulling is an early step in which the outer coating (hull) is removed (figure 1). Oat hulls are thus a by-product that is mostly used as a renewable energy source. The hulls are easy to remove because they are not tightly bound to the kernel. Mechanical processes are used to crack the hulls and the grains that are not cracked in the first attempt are subjected to a second round. Several rounds may be needed before all hulls are removed. The dehulled oat grains (also called raw groats) are collected and used in further processing steps, while the oat hulls are collected and sent for incineration (Hareland et al. 2003).

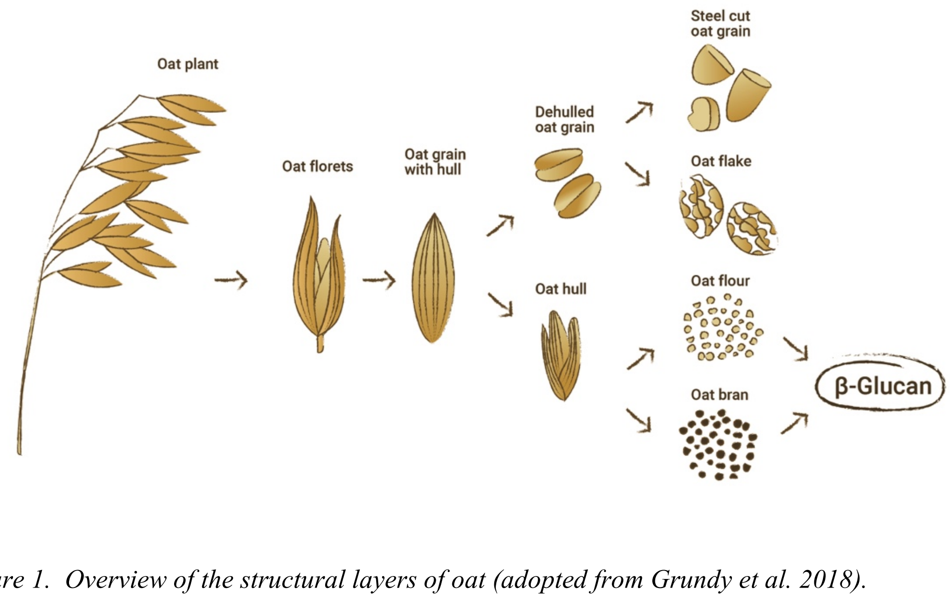

Figure 1. Overview of the structural layers of oat (adopted from Grundy et al. 2018).

2.2.1.1 Dietary fibre content

Dietary fibres (DF) are defined as "carbohydrate polymers with three or more monomeric units (to exclude mono- and disaccharides) which are neither digested nor absorbed in the small intestine" by the European Union (commission Directive 2008/100/EC, 28 October 2018). The consumption of dietary fibre (DF) has a beneficial impact on the consumer (Prasadi et al. 2020). The link between dietary fibre intake and health benefits is well established, as they serve as nutrition (prebiotic) for the bacteria in the colon. As DF is highly present in cereals, they are important contributors to human DF intake, accounting for about 50% of the total intake in the Western world. Although the benefits of DFs are well recognised, the population's intake of DFs is below the recommended levels (Prasadi et al. 2020, Livsmedelsverket 2023). Different cereals have different amounts of DFs, and different compositions of soluble dietary fibres (SDF) and insoluble dietary fibres (IDF). Oat SDF is mostly composed of β-glucan and is present in high amounts in the endosperm cell walls (Prasadi et al. 2020). However, oat hull DFs are mainly insoluble and contain large amounts of lignocellulose (up to 83%), which is a material with three main components: cellulose, hemicellulose and lignin. (Schmitz 2022). Hemicellulose from cereals is sought after because it can be used as a fibre supplement in food (Ravindran et al. 2016). The hemicellulose arabinoxylan accounts for 35% of the DF in oat hulls. IDFs act mainly as a bulking agent and laxative, reducing intestinal constipation (Prasadi et al. 2020). Alternatively, the hemicellulose can be broken down into smaller parts, *i.e* become more available to the bacteria in the gut and thus act as prebiotics (Schmitz et al. 2020). To achieve this, some processing must be done. Schmitz (2022) used enzymes (xylanases) to shorten the structure of the fibres. This pre-treatment was followed by a bleaching process, where the rough texture, dark colour and unpleasant taste caused by the high percentage of SDF, were remedied (Schmitz 2022).

2.2.2 Bleaching

Since the addition of oat hulls in food products results in a dark colour of the product, some adjustment needs to be made in order to increase consumer acceptance (Schmitz 2022). Bleaching of the oat hulls is a way to lighten the colour. In addition, unwanted odours and flavours are removed by this procedure. There are three different kinds of methods that can be used for bleaching: biochemical methods, reducing methods, and oxidizing methods. It is important to consider whether the method used to bleach food components is safe in terms of the environment, workers, nutritional content, and edibility (Schmitz 2022).

The oat hulls used in this project were bleached according to Schmitz (2022). Hydrogen peroxide, an oxidant used in the bleaching process, is a well-known oxidizing agent used for bleaching. It does not change the chemical composition or nutritional value of the product but provides an effective bleaching result. This is of utmost importance as the hulls in this project are expected to provide nutritional value in the form of dietary fibre in bread. In addition, alkaline hydrogen peroxide contributes its antimicrobial effect, making the process even more effective. The only by-products of this bleaching process are oxygen and water. Therefore, the alkaline hydrogen peroxide treatment method is ideal for oat hulls (Schmitz 2022). In Schmitz's study, a dry matter of 35% was used. However, the oat hulls used in this project had a dry matter of 8%, which affected the bleaching process by making the hull colour less light. Therefore, the role of particle size on oat hull colour is investigated in this project.

2.3 Analysis methods

2.3.1 Farinograph

The farinograph is a well-known tool for measuring rheological dough properties (Wrigley et al. 2022). It measures the resistance of the dough while mixing, which is measured in Brabender Units (BU). However, the farinograph can also be used to determine other dough properties such as the water absorption of the flour (Wrigley et al. 2022).

2.3.2 Colour measurement

The colour of food gives an important first impression and shows how fresh it is or gives an indication of how it has been processed (Markovic et al. 2013). Measuring the colour of a food product can be of interest in several different contexts. A spectrophotometer is used to measure colour. It measures the Lab colour system, which is the most common technique used when measuring food colour because it mimics the human eye (Markovic et al. 2013). The L-value represents the lightness of the sample, where 0 is black and 100 is white (Warner 2014). The higher the L-value, the lighter the colour. The a-value is a measure of where the colour is on the green-red axis. A positive value means red tones while a negative value means green tones. The position of the colour on the blue-yellow axis is shown by the b-value. Yellow tones give positive values and blue tones give negative values (Warner 2014).

2.3.3 Texture profile analysis

Food texture is an important parameter for the assessment of product quality (Young 2012). The definition of food texture according to the International Standards Organization (ISO) is "All the rheological and structure (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors" (ISO 2020). Texture is crucial for consumer liking, along with visual appearance, taste and flavour. Therefore, optimizing texture to suit human preferences is of utmost interest for food development and production. Food texture can be measured both objectively (mechanically) and subjectively (human panel), and the two are often combined (Young 2012).

Texture Profile Analysis (TPA) is a common technique for measuring the texture of solid and semisolid foods objectively. This technique uses compression testing with two-bites to mimic the bite of the teeth (Rosenthal 2010). An advantage of this analysis is that it measures several different parameters simultaneously. It takes into account the complexity of food texture and human preferences (Young 2012).

TPA measures multiple parameters such as hardness, firmness, softness, springiness, and cohesiveness, terms that were defined by Szczesniak et al. (1963). When measuring the texture profile of bread, cohesiveness and springiness are desirable attributes (Szczesnial et al. 1963, Young 2012). Cohesiveness refers to how much pressure the product can hold before it breaks. This depends on the moisture content of the bread and the strength of the network encircling the holes in the bread crumb. Springiness is defined as how much the product needs to return to its original shape after being subjected to pressure. Hardness is another parameter measured in bread. It is used as an indicator of freshness, depending on how the bread reacts to pressure (Young 2012). It is defined by the force needed to make the first compression. Consumers usually squeezes the bread in the supermarket to determine whether the bread is fresh or not (Szczesniak et al. 1963). A summary of the textural parameters measured in this study (hardness, cohesiveness and springiness) can be seen in table 1.

An instrument commonly used to measure these parameters in food is the texture analyser (TA). A probe is attached to the TA, which is moved up and down monitored by a force transductor. The probe deforms the product sample and transmits the deformation data to the force transductor, generating a force-time curve (Young 2012). Figure 2 shows a typical example of such a curve from a double compression test for breadcrumb. In these tests, a slice of bread at a specific depth is used to measure the inside of the loaf.

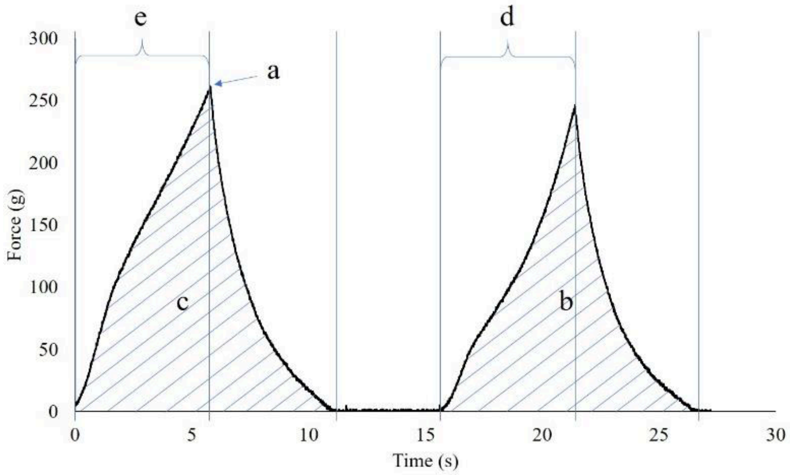

Figure 2. Typical force-time curve obtained from a TPA. a: peak force of first compression; b: area of second compression; c: area of first compression; d: distance of second compression; e: distance of first compression.

Table 1. Textural parameters obtained from a TPA

Textural parameter	**Physical definition (Szczeniak 2002)**	**Sensory definition (Szczeniak 2002)**	**TPA definition (Bourne 2002a)**	**In figure 2**
Hardness	Force needed to obtain a certain deformation	Force needed to compress food between molars	Peak force value of first compression	a
Cohesiveness	Degree of deformation before rupture of sample	Extent of compression of food between teeth before rupture	Ratio between force areas of second and first compression	b/c
Springiness	Rate of recovery after deformation of sample	Degree of recovery to original shape after compression between teeth	Recovered height of the sample between the two compressions	d/e

2.3.4 Image analysis

Image analysis is basically a way to obtain useful information about a product from a digital image using a software (Lu et al. 2017). It can be performed by a trained eye, by comparing the images with the Dallman scale (Bot et al. 2014) or a digital image analysis can be performed. Digital image processing is a reliable and efficient method used on food products such as bread. Image analysis of breadcrumb structure is done to determine, for example, total cell count, cells per area, and average cell size (Young 2012). The idea is to objectively assess the structure and quality of breadcrumbs. The technique is used to extract information from digital images by separating pixels based on colour or intensity. To separate the object from the background, thresholds are used. It is a method used to separate the cells of the breadcrumb from the walls of the crumb. Then, the part of the image to be analysed is selected and the desired values are presented (Zghal et al. 1999).

2.3.5 Sensory analysis

In order to complement the mechanical analysis, a human sensory test is often carried out as an addition. Sensory evaluation has been used in the food industry since the 1950s (Stone et al. 2020).

Sensory evaluation is not only an important tool when developing new products, but also if a product is entering a new market or is expected to compete in existing markets (Stone 2018). It measures all sensory properties of a product using a human panel or a consumer group, and is evaluated through sight, hearing, touch, smell, and taste (Gustavsson et al. 2019).

There are two types of sensory tests: analytical tests, which are objective and require a trained panel, and affective tests, which are subjective. In an affective test, there is no need for a trained panel. However, it is preferable if the panel consists of regular consumers of similar products and thus the target group of the future product (Gustafsson et al. 2019).

At the 1950s, procedures for ranking and hedonic scales started to be used more frequently (Stone et al. 2020). Difference testing is an analytical test where the panel is used to determine if there is a general difference between the samples (Gustafsson et al. 2019). A triangular taste test is one kind of difference test where you have three samples and two of them are identical. The panel tastes the samples in a given order and determines which of the sample that is different. It is a forced choice test, which means that the participants cannot leave the form blank. The number of testers in a triangle test is recommended to be 20-30 people (Gustafsson et al. 2019).

3. Material and Methods

3.1 Material

Special wheat flour (Kungsörnen) was used in this project. The flour contained wheat flour, malt flour from barley and ascorbic acid. The protein content was 12% and the fibre content was 3.5%. The reference fibre used in this project was VITACEL® Havrefiber HF 600. It is a light, finely milled dietary fibre concentrate extracted from oat spelt bran (Rettenmaier et al.). It is known to not add any off-flavours or odours to the product it is added to.

The bleached oat hulls, the special wheat flour and the reference fibre used for baking was provided by Lantmännen R&D. Remaining ingredients: yeast, oil, sugar and salt were purchased at a local supermarket.

All laboratory work was carried out at SLU´s premises, using their equipment.

3.2 Raw material preparations

3.2.1 Milling and sieving

Milling

In order to use the bleached oat hulls for baking, they first needed to be milled. Two test millings were done with a Retch mill at different rotation speeds. Then a final test milling was done with a table mill, Fidibus Classic, which were used further on. The bleached oat hulls were milled into two different flours by combining different settings on the table mill until there was a finely milled flour and a slightly coarser flour.

Sieving

In order to determine the particle size of the two different milled oat hull flours, they were sieved in a Retsch Test sieve, ISO 3310-1, Serial No 08041089 for 7 minutes, with 10 seconds intervals, at 1.5 amplitude mm/" g". The sieves used were of the following sizes: 50 µm, 75 µm, 150 µm, 250 µm, 425, and 600 µm. The collected fractions were weighed, and the percentage of each fraction was calculated.

3.3 Bread baking

Bread loaves were baked with addition of the different raw materials: coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF). These were added at three different levels: low (L), representing 1.3% added fibre, medium (M), representing 2.7% added fibre and high (H), representing added 4% fibre. To obtain the same fibre addition for the different raw materials, the amounts added were adjusted (table 2).

Table 2. Different amounts of the different raw materials (coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF)) used in the bread recipe to obtain a fibre content of 1.3%, 2.7% or 4%.

Amount raw material added			Obtained fibre content added
OHC	OHF	RF	
3.5 g	3.5 g	3.3 g	1.3%
7.1 g	7.1 g	6.7 g	2.7%
10.6 g	10.6 g	10 g	4%

For the breadmaking, the recipe used was as follows: 225 g of special wheat flour (including eventual addition of oat hulls or reference fibre), 10.4 g yeast, 5.6 g rape seed oil, and 11.3 g sugar and 3.4 g salt, both in solution. Additionally, a variable amount of 37° warm water was added to reach a resistance of 400 BU when the dough was mixed in the farinograph (for description see below) (for water amounts see appendix 2).

The dough was prepared in a farinograph mixing bowl. Firstly, the flour with the eventually added oat hull or reference fibre was mixed for 1 minute. Thereafter, the yeast, sugar- and salt solution, oil and lastly the remaining water were added. The water content varied due to the different hull/fibre additions. When the first replicate of each dough was made, water was added little by little until 400 BU was reached on the farinograph. The same amount of water was then used in the remaining replicates. Once prepared, the dough was transferred to a ceramic bowl, covered with a kitchen towel, and placed in a proofing oven at 35 °C, 50-60% relative humidity for 1 hour. The dough was then weighed into three 100-gram doughs, rolled in an extensograph rounder (Brabender GmbH & Co KG, Duisburg, Germany, for 20 rotations and placed in small, lightly greased baking tins. They were then returned to the proofing oven for 1 hour. Finally, the doughs were baked in a baking oven at 240°C for 10 minutes. Steam was injected into the oven for 3 seconds on two occasions. First, at the beginning of baking and then after 5 minutes. The baked breads were taken out and covered with a kitchen towel to cool for 1 hour before packed in a plastic bag.

3.4 Experimental design

A Completely Randomized Design (CRD) was used in this project. The study consisted of two independent factors at three levels: 1) Particle size (coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF), reference fibre (RF). 2) Addition level (Low (L), Medium (M) and High (H)) (figure 3). The levels refer to how much fibre that was added for the different raw materials. As the fibre content differs between the reference fibre (90%) and oat hulls (85%), the addition of raw material varied in the recipe (table 2). Additionally, three control doughs (*i.e* without fibre addition) were made. All doughs were made in triplicates. Each dough was shaped into three small loaves, which were used in the different analyses.

	Raw material			
Levels	**Coarsely milled bleached oat hulls (OHC)**	**Finely milled bleached oat hulls (OHF)**	**Reference fibre (RF)**	**Control**
	Low (L)	Low (L)	Low (L)	
	Medium (M)	Medium (M)	Medium (M)	
	High (H)	High (H)	High (H)	miro

Figure 3. An overview of the experimental design.

Generally, during baking days, three random doughs were prepared, divided into three loaves, and baked. After cooling, the loaves were stored in plastic bags. All analyses were done on the day after baking (day 1), starting with texture analysis. Thereafter, two bread slices from the same bread were scanned to be used for image analysis. Lastly, weighing, volume, and colour measurements were done. For these analyses two bread loaves were used.

3.4.1 Additional baking

One additional baking was performed, which was excluded from the experimental design. The purpose of this baking was to evaluate how a higher amount of fibre would affect the properties of the bread. The same recipe as above was used (section 3.3), but a very high (VH) level of fibre (8%) was added. Breads baked with OHC, OHF or RF were prepared and analysed (specific volume, colour and image analysis).

3.5 Analyses

3.5.1 Water holding capacity

In baking, the water holding capacity (WHC) of the flour is of great interest (Berton et al. 2002). It is a measure of the flour's quality and its ability to form a useful viscoelastic dough. The functional characteristics of baking products are also impacted by the WHC (Berton et al. 2002). In order to use oat hulls in bread baking, it is therefore of utmost interest to investigate how the WHC differs between the different fractions of oat hulls, and also how they relate to the reference fibre.

The water holding capacity of the milled oat hulls was determined according to AACC Method 56-20. The quantities in the method were halved in this test. Thus, 1 gram of sample and 20 ml of water were used. Sample and water were added to test tubes and shaken vigorously. They were then left for 10 minutes in room temperature and shaken again after 5 and once more after 10 minutes. To press the water out of the samples, they were centrifuged at 1000×g for 15 minutes. The sediment was weighed, and the hydration capacity was calculated by the formula:

$$\text{Hydration capacity} = \frac{\text{(weight of sample + sediment) - (weight of tube)}}{\text{sample weight (dry basis)}}$$

3.5.2 Colour measurement

In this study, the colour of the different milled fractions was of interest to investigate its relationship with particle size. When measuring the colour of the bread, the reason was to investigate the effect of the amount of added milled oat hulls, but also if the particle size of the oat hulls affected the results.

The colour of the milled oat hulls as well as the unmilled oat hulls was measured with a spectrophotometer (CM-600D; Konica-Minolta, Osaka, Japan). Three measurements were taken on each sample and the means were calculated. The colour of the reference fibre was also measured.

3.5.3 Dietary fibre content

Content of dietary fibre (DF) and their components in the bleached oat hulls were determined according to the Uppsala method (AOAC Method 994.13) (Theander et al. 1995). The sample was analysed in duplicate, and the result is reported as an average value on dry weight basis. Dry matter content was determined by drying the samples at 105°C for 16 h. Results can be seen in appendix 1.

3.6 Bread Analyses

Bread analyses were done on day 1. First, the texture analyse was performed, followed by the scanning of two bread slices to be used for image analysis. Finally, the bread loaves were weighed, and the volume and colour were measured.

For the additional baking, specific volume, colour measurement, and image analysis were performed.

3.6.1 Specific volume

Bread volume was measured using seed displacement method AACCI 10-05.01. This was done at day 1. The bread loaves were weighed after slicing. By dividing volume by weight (ml/g), specific volume was calculated.

3.6.2 Colour measurement

The colour of the bread loaves was measured with a spectrophotometer (CM-600D; Konica-Minolta, Osaka, Japan) at day 1 (figure 4). The measurements were done on both the crumb and the crust. Three measurement points were selected on the crumb and crust respectively. The L*a*b* values were collected. Means and standard deviation were calculated in Excel.

Figure 4. Images from crumb structure analysis. From left image before processing, image in 8-bit format, image after processing, ready to be analysed.

3.6.3 Texture profile analysis

To analyse the texture profile, a 2.5 cm slice of bread was manually cut out from the centre of each loaf on day 1 and used for TPA analyse in a TA (TAplusDi, Stable Micro Systems) using a 50 kg load cell and a 50 mm cylinder aluminium probe. Each bread slice was centred on the base and compressed to 40 % of the height in two cycles (5 s between compressions). The collected data was processed through Texture Expert Exceed software (Stable Micro Systems).

3.6.4 Image analysis

Image analysis was carried out on the bread slices to get an overview of the average cell size and the percentage surface area occupied by the pores. Two slices of the bread were scanned in a photocopier (Ricoh IM C5500). The pictures were processed and analysed with the software ImageJ/Fiji. The images were cropped to the edges of the bread slice, converted to 8-bit format, segmented with the Percentile auto-threshold and subjected to the binary watershed process (as can be seen in figure 4). A square in the centre of the image was analysed after the edges had been cut away. The analysed area was therefore individual for each image. The parameters obtained were percentage area and average cell size. Two slices of bread from each batch were analysed.

3.6.5 Sensory evaluation

A sensory analysis was conducted by two randomised triangle taste tests at SLU, Ultuna. The room used was light and neutral with white walls, tables, and chairs (picture in appendix 4). There were 20 participants taking part in the evaluation. The participants were students, researchers and workers, everyone consume bread regularly. Each participant sat at a separate table to be able to focus on the given task. The test was conducted in two parts. In the first part a bread with a 4% addition of bleached oat hull fibre was compared to a bread with a 4% addition of the reference fibre. In the second part, a bread with 2.7% added bleached oat hull fibre was compared to a control bread baked with 100% special wheat flour. Each participant received a plate with three samples of bread, randomized coded (picture in appendix 4 and appendix 5). Two samples were identical, and one was different. A form was filled in by each participant and collected when everyone had finished.

3.6.6 Statistical analysis

Data were analysed statistically using Minitab®19. Analysis of Variance (ANOVA) with a General Linear Model (GLM) was performed for all result values from the bread analyses. The raw materials, levels, and the interaction between the two were analysed using Tukey´s pairwise comparison. Only significant interactions were included in the final models. All values are reported as mean values. P-values <0.05 are considered significant. For the sensory evaluation, a result processing table for difference tests (Gustafsson et al 2019) was used to determine if possible significant differences were present at a significance level of 5%.

4. Results and Discussion

As there is a side stream of oat hulls from oat production that can be reused more efficiently, a product containing these hulls is of interest. Due to the high fibre content of oat hulls, they would be beneficial for human consumption. Adding oat hulls in a bread would be a convenient way to utilize them. In this project, the hulls have been bleached to make them more acceptable to the consumer and this project investigates their effect on bread properties have been investigated. The following section of the report presents and discusses the results.

4.1 Milling and sieving

In order to use the oat hulls for baking it was necessary to mill them. As can be seen in figure 5, the unmilled hulls (on the right) are very coarse and would not be accepted in a baked product. It would both disrupt the gluten network in the dough and be extremely unpleasant to chew and swallow. The coarsely milled hulls (middle) had some structure, while the finely milled hulls (on the left) were like a smooth powder.

Figure 5. The bleached oat hulls. From left finely milled, coarsely milled, and unmilled.

In order to compare particle size of the milled oat hulls with the reference fibre, sieving was performed. The results of the sieving are shown in figure 6. The finely milled oat hulls and the reference fibre both had largest proportion, 40% and 43% respectively, of the 50-75 µm particle size, making them the most similar and also the most powder-like. This is an indication of that the finely milled hulls could be a qualified candidate to replace the reference fibre in bread production. The content of the coarsely milled oat hulls was mainly 150-425 µm particles. The unmilled oat hulls consisted of 40% of particles with a size at >600 µm and the rest had a lower particle size. No particles smaller than 50 µm were found in the unmilled hulls and therefore not visible in the figure.

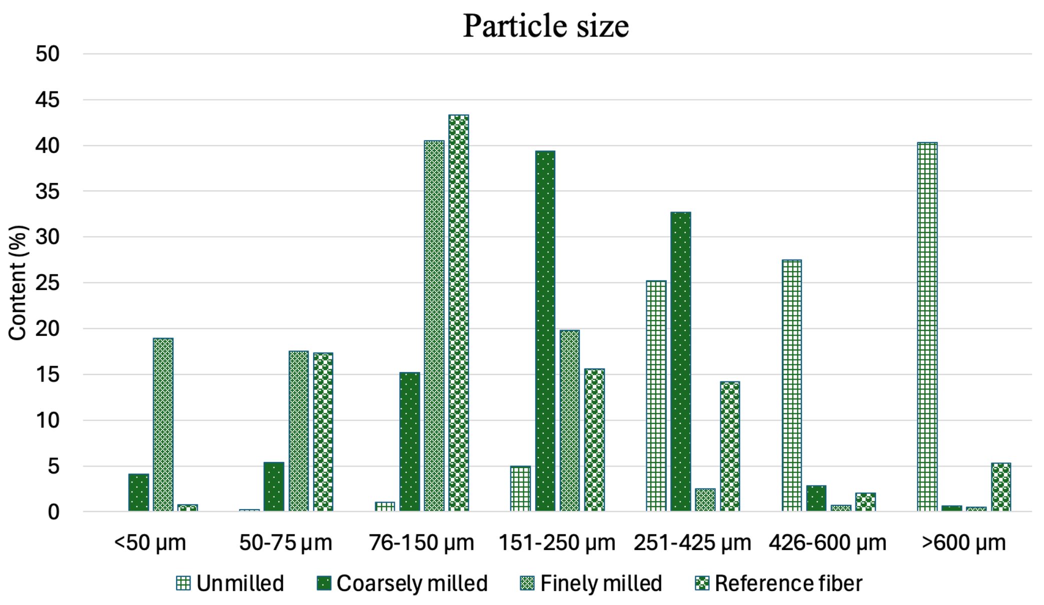

Figure 6. The content distribution of the different particle sizes of the unmilled bleached oat hulls, the coarsely milled bleached oat hulls, the finely milled bleached oat hulls together with the reference fibre.

4.2 Raw material analyses

4.2.1 Water holding capacity

AACC Method 56-20 was used to determine the water holding capacity (WHC) of the unmilled bleached oat hulls, the finely milled bleached oat hulls, the coarsely milled bleached oat hulls and the reference fibre. The reference fibre had the highest value of 4.93 g water/1.0 g solid (table 3). The WHC of the finely milled oat hulls and the unmilled oat hulls had similar values, although the standard deviation was larger for the unmilled oat hulls. The lowest WHC was found in the coarsely milled oat hulls with a value of 3.78 g water/1.0 g solids (table 3).

Table 3. The water holding capacity (WHC) of the unmilled, coarsely milled, and finely milled bleached oat hulls, and the reference fibre. The values are presented in g water/1.0 g solid as average values ± standard deviation

Sample	WHC (g water/1.0g solids)
Unmilled	4.49±0.09
Coarsely milled	3.78±0.02
Finely milled	4.38±0.04
Reference fibre	4.93±0.03

As WHC of a flour is a way to measure its ability to form a viscoelastic dough and thus its quality, it is a very important factor to investigate. WHC also affects the functional properties of the baked bread. These results show that the oat hulls had a WHC similar to the reference fibre. This is a desirable result if the reference fibre is to be replaced by oat hull fibre in bread production. The reason why the standard deviation was greater for the unmilled oat hulls was probably because they contain larger particles. More water was trapped by the large particles and therefore probably prevented from coming out when the tube was emptied.

4.2.2 Colour measurement

The colour of a food product is essential for consumer liking. A light colour of a bread is more acceptable and therefore it was interesting to investigate both the influence of milling on the colour of the flours, but also if there was a correlation between the flour colour and the colour of the breads (see section 4.3.2).

To compare the colour of the different milled oat hulls, a spectrophotometer was used. Table 4 presents the colour measurements (L-value, a-value and b-value) on the bleached oat hulls together with the reference fibre. The highest level of lightness (L-value) was found in the reference fibre (87.74), followed by the finely milled hulls (85.07). The lowest L-value was found in the unmilled hulls (79.19). This indicates that the lightness of the raw material is affected by the degree of milling. The smaller the particles, the lighter the material, *i.e* more surface to reflect light.

*Table 4. L*a*b* values of the different milled bleached oat hulls, the unmilled bleached oat hulls and the reference fibre, measured with a spectrophotometer. Negative a-values represent green tones, while positive a-values represent red tones. Positive b-values represent yellow tones*

	L	a	b
Unmilled	79.19±0.23	0.40±0.07	29.21±0.83

Coarsely milled	83.17±0.09	-1.11±0.03	22.56±0.23
Finely milled	85.07±0.09	-1.55±0.03	19.22±0.42
Reference fibre	87.74±0.10	-0.51±0.01	7.59±0.05

± indicates standard deviation

The a-values represent the colour from green (negative values) to red (positive values). The results show that the unmilled hulls had some red tones (0.40), while the milled hulls and the reference had some green tones (table 4). The finely milled had the greenest tone (-1.55) and the reference fibre had the least green tone (-0.51). The milling thereby influenced the greenness of the materials. They went from a slightly red tone in the unmilled hulls to a slight green tone in the two milled ones. It is possible that this is a result from the heat generated by the stone mill during the milling process. There also seem to be a correlation between freshly milled flour and greenness. According to Bakerpedia (2024) green wheat flour is a immature or freshly milled flour that has not had time to age. When flour ages, oxygen triggers physiochemical reactions to occur. Among these reactions is the oxidation of yellow carotenoids. The green tone would thus decrease over time. To find out if this was the case for the milled oat hulls, colour measurements were performed on the materials again, three months later. The a-value of OHC had decreased to -0.77 (from -1.11), and the a-value of OHF had decreased to 1.37 (from -1.55). The other values were still the same as in the first colour measurement. This indicates that the hypothesis that the greenness of freshly milled flour decreases with time was correct for the milled oat hulls.

The b-values represent the colour from blue (negative values) to yellow (positive values). All samples had yellow tones, including the reference fibre, although the highest b-value was measured in the unmilled hulls (29.21) (table 4). The yellowness was also affected by the milling, as clearly shown in figure 5. The smaller particles, the less yellow material, resulting in the lowest b-value (7.59) being found in the reference fibre.

In conclusion, it is possible to influence both lightness and colour of the oat hulls by milling.

4.2.3 Dietary fibre content

The content of dietary fibre in the bleached oat hulls were determined to be 81,8%, of which over 82% of the total DF was insoluble (appendix I). The reference fibre had a dietary fibre content of 90% according to the specification provided with the product. Compared with wheat and rye hulls, which contain 70% and 55% dietary fibre respectively, oat hulls are extremely high in fibre (Bledzki et al. 2010).

4.3 Bread Analyses

As the visual appearance of the bread loaves did not differ much (figure 7), physical and sensory analyses were needed in order to evaluate the effect of the different additives. Thus, specific volume, colour, texture, crumb structure and taste were analysed. The results are presented and discussed in the following pages.

Figure 7. Bread loaves baked with high levels of oat hulls or reference fibre. From left control (no additive), fine oat hulls, coarse oat hulls, and reference fibre.

For the bread analyses, analysis of variance (ANOVA) was used to analyse whether there were any significant differences between the raw materials, addition levels, or the combination of the two. The results from the ANOVA were summarised and are presented in tables 5 and 6. Further discussions refer back to these tables.

Table 5. Analysis of variance. P-values for significant effects of raw material and addition level, as well as interactions for measured parameters

	Raw material	Level	Raw material x Level
Specific volume	ns	ns	ns
Colour crumb L	0,047	ns	ns
Colour crumb a	0,004	0,035	ns
Colour crumb b	0,000	0,000	0,002
Colour crust L	ns	0,007	ns
Colour crust a	0,001	ns	ns
Colour crust b	ns	0,032	ns
Texture hardness	ns	0,004	ns
Texture cohesiveness	ns	0,007	ns
Texture springiness	ns	ns	ns
Image average cell size	ns	ns	ns
Image %area	0,01	ns	ns

ns = not significant

Table 6. Specific volume (ml/g), colour measurement, texture analysis, and image analysis for different raw materials and addition levels. Different letters in same row of each category (vertical division) show significant difference between values. Data are presented as mean values. The control was not included in the experimental design

	Raw material			**Addition Levels**			**Control**
	Coarse	Fine	Reference	Low	Medium	High	
Specific volume	3.98^{a}	3.96^{a}	3.91^{a}	4.11^{a}	3.89^{a}	3.85^{a}	4.27
Colour crumb L	76.81^{ab}	77.31^{b}	78.24^{a}	77.53^{a}	77.82^{a}	77.01^{a}	78.27
Colour crumb a	0.35^{b}	0.34^{b}	0.45^{a}	0.33^{b}	0.38^{ab}	0.42^{a}	0.43
Colour crumb b	18.30^{b}	18.93^{c}	17.27^{a}	17.33^{a}	18.19^{b}	18.99^{c}	16.49
Colour crust L	49.25^{a}	49.05^{a}	50.71^{a}	48.26^{b}	48.72^{b}	52.04^{a}	48.38
Colour crust a	13.45^{a}	13.51^{a}	12.77^{b}	13.34^{a}	13.29^{a}	13.11^{a}	14.03
Colour crust b	27.41^{a}	27.78^{a}	27.23^{a}	26.85^{b}	27.25^{ab}	28.32^{a}	27.76
Texture hardness	8.96^{a}	9.43^{a}	10.27^{a}	8.50^{b}	9.49^{ab}	10.67^{a}	8.02
Texture cohesiveness	1.43^{a}	1.41^{a}	1.43^{a}	1.39^{b}	1.43^{a}	1.44^{a}	1.42
Texture springiness	1.06^{a}	1.06^{a}	1.05^{a}	1.06^{a}	1.06^{a}	1.06^{a}	1.04
Image average cell size	36.44^{a}	35.77^{a}	39.43^{a}	38.72^{a}	35.45^{a}	37.48^{a}	33.03
Image %area	16.76^{b}	16.40^{b}	19.97^{a}	19.13^{a}	16.72^{a}	17.28^{a}	12.65

4.3.1 Specific volume

Adding dietary fibre can negatively affect the volume of bread. High bread volume is usually considered a positive parameter in bread. Therefore, it was interesting to investigate the impact of the different fibre additives on the specific volume.

The specific volume of the bread loaves was calculated by dividing the volume of the bread by the weight of the bread. There was no significant difference in specific volume between any of the samples (table 5). However, there was a trend of decreasing volume with increasing amount of added oat hulls or reference fibre (figure 8). The bread baked with medium level of the reference fibre had an anomalous value of 3.66 ml/g, which was the lowest value measured. The reason for this is unclear, but the human factor and the surroundings can be considered as contributing factors. The control bread, baked with 0% fibre, had the highest specific volume, which was expected. Remarkably, the bread loaves baked with low level of the finely milled bleached oat hulls had almost the same value as the bread loaves baked with low level of the reference fibre. The bread baked with the coarsely milled bleached oat hulls competed with the bread baked with the reference fibre for the highest specific volume at high fibre addition (figure 8). The fact that there was no significant difference between any of the samples is either an indication that the oat hulls and the reference have the same impact on bread volume or an indication that the amount of fibre added was not high enough to determine a significant difference between the two.

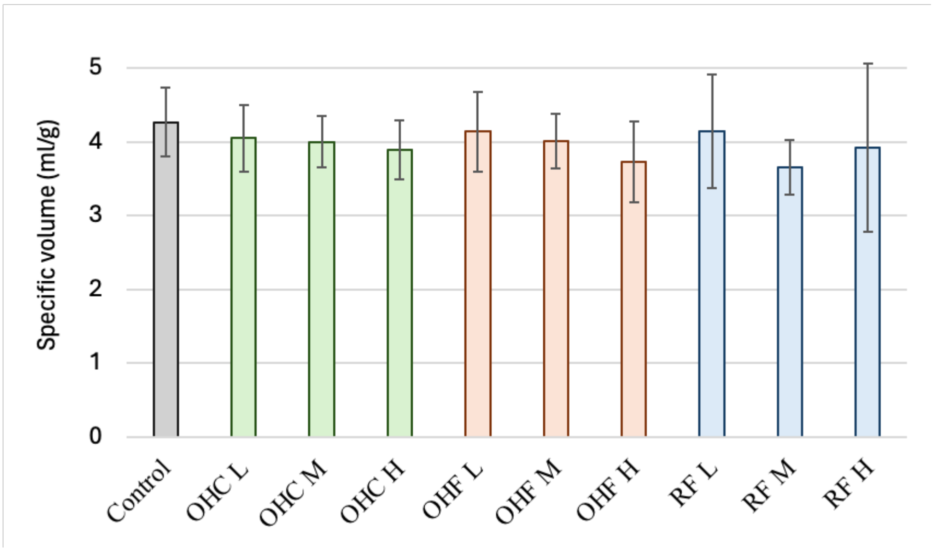

Figure 8. Specific volume for bread loaves baked with coarsely milled bleached oat hulls (OHC) finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels. The control is also included in the figure.

4.3.2 Colour measurement

Bread crumb

The spectrophotometer was used on the baked bread loaves in order to compare the colour of the different batches and to determine whether the results of the colour measurements of the raw material was reflected in the baked bread. The measurements were done on the crumb of the bread loaves. The different addition levels did not result in any significant difference. However, the lightness of the breads was significantly different between the raw materials (table 5). The breads baked with reference fibre differed significantly from the breads baked with finely milled oat hull fibre. This means that the bread baked with reference fibre was lighter than the breads baked with fine oat hulls. This is consistent with the results of the colour measurements of the raw material. As can be seen from figure 9, there was a trend of slightly decreasing lightness with increasing fibre content for both the bread baked with the fine oat hulls and the reference fibre. This was to some extend expected as the raw material followed the same pattern. The bread baked with coarse oat hulls had overall lower L-values than the other breads, but not significantly different, which show the same results as for the raw material measurements and thus again demonstrating the relationship between particle size and lightness.

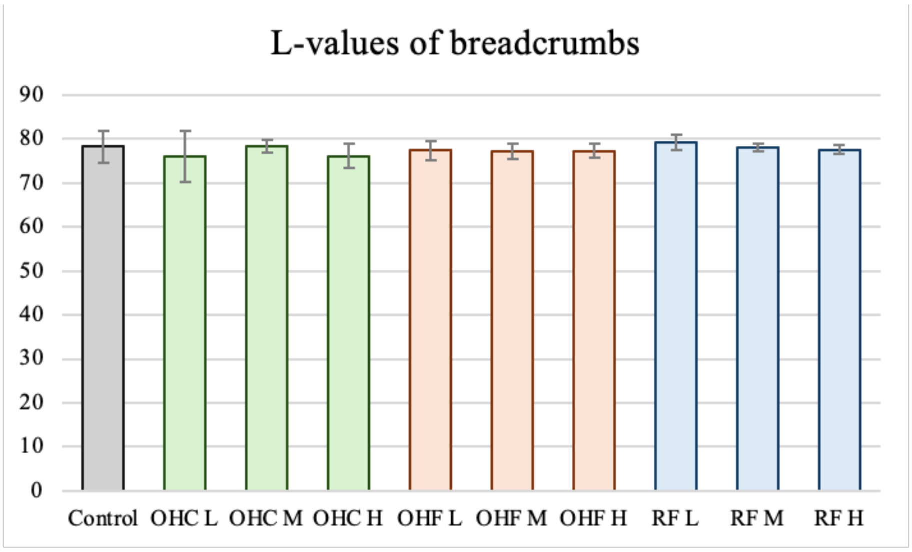

Figure 9. Lightness of bread crumb of loaves baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels, plus a control bread, presented as L-values.

As shown in figure 10, all breadcrumbs measured positive a-values, which means that all breadcrumbs had red tones. The trend in both the bread baked with reference fibre and the bread baked with coarse oat hulls was that the redness of the bread increased with increasing addition. The bread baked with fine oat hulls almost followed the same trend, with the exception of the value for the bread with medium addition. However, when considering the results for the breads with OHF M, the SD was larger than for the breads with OHF L and OHF M. *i.e* the variation between the measured values was thus greater, suggesting that a high value may have pushed up the mean. The highest a-value was found in the breads baked with the reference fibre at high level (0.51) (figure 10). The a-values were significantly different for both raw material and level (table 5). For the raw material, the breads baked with reference was significantly different from breads with both coarse and fine oat hulls added. Thereby, the addition of reference fibre resulted in a slightly more red toned bread than the oat hulls. Since the milled oat hull flour had more green tones than the reference fibre flour before baking, this was an expected result. The breads with low and high addition levels differed significantly from each other, while the medium level did not differ significantly from any of the others. This indicates that increasing addition of oat hulls or reference fibre also has an impact on the redness of the bread crumb (table 5 & figure 10).

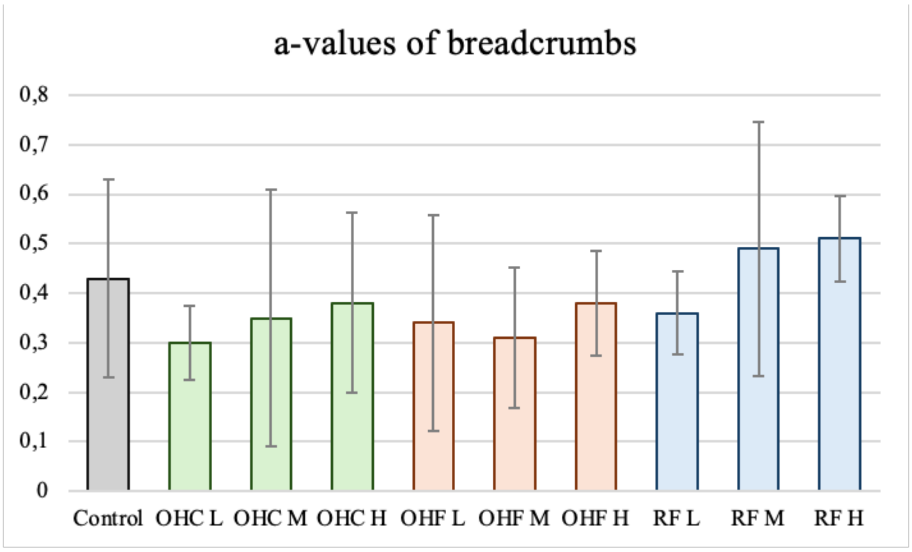

Figure 10. a-values representing the colour from green (negative values) to red (positive values), of the crumb of bread loaves baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) and high (H) levels, plus a control bread.

The b-values of the breadcrumbs measured yellow tones in all breads (figure 11). The yellowness increased significantly with increasing fibre content for all breads, although the differences were smaller for the reference breads (figure 11 and table 5 and table 6). This is probably because the reference fibre flour was not nearly as yellow as the oat hull flours before baking (table 3). The bread baked with OHF H had the highest b-value (20.04) and the control bread had the lowest b-value (16.49). Considering the measurements of the raw materials, these results were not surprising. For the b-values, there were significant differences between all samples, both for raw materials and for levels (table 5 and 6). This indicates that the type of added fibre, as well as the amount affected the yellowness of the breads. Moreover, the only combination effect (raw material x level) in this project was measured in these values (table 5). The two parameters were thus also under the influence of each other.

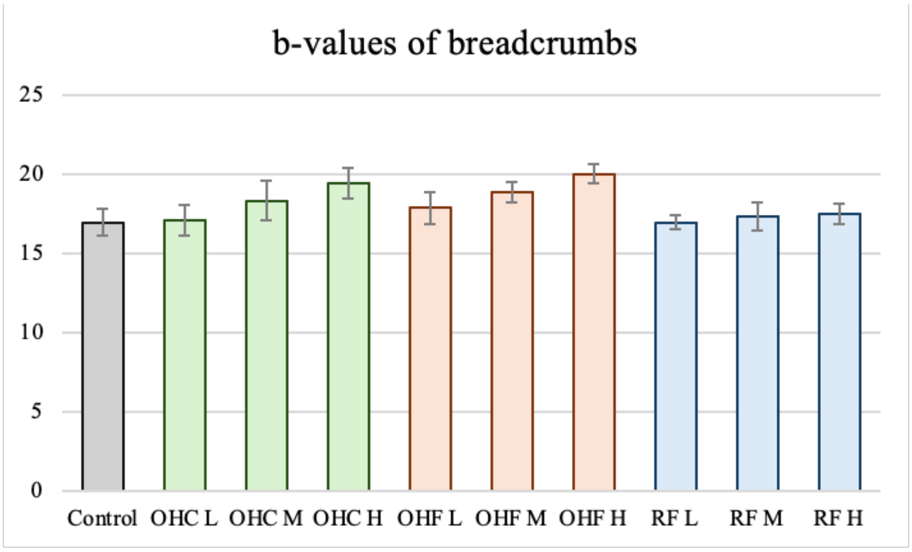

Figure 11. b-values of the bread crumb from bread loaves baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels, plus a control bread. Negative values represent blue tones and positive values represent yellow tones.

Bread crust

For the bread crust, the ANOVA results presented in tables 5 and 6 show no significant difference between the raw materials considering the L-value, *i.e* there was no difference in lightness. On the other hand, the breads baked with high level addition levels were significantly different from the breads baked with low and medium addition levels. This means that the lightness increased significantly with higher levels of oat hulls or reference fibre. The lowest a-value was found in the reference bread, in other words, the addition of reference fibre made the bread crust less red than the addition of oat hulls. This indicates that a larger Maillard effect occurred in the breads baked with oat hulls during baking. No significant difference was observed between the different addition levels for the a-values. For the b-values, the raw material had no significant effect. However, the low addition level was significantly different from the high addition level. Although the values were significantly different, it is worth considering whether this actually has an impact on the perception of the breads.

4.3.3 Texture profile analysis

The texture profile of the different samples is shown in figure 12-14.

Hardness

In terms of hardness, there were no significant differences between breads baked with different raw materials (table 5 and 6), *i.e* the hardness of the breads was not dependent on which form of fibre that was added (table 5). However, the highest value was found for the bread baked with the high level of reference fibre (figure 12), although the variation between replicates was greatest in this sample. There was a trend of harder breads baked with reference fibre than of breads baked with oat hulls. Not surprisingly, the hardness of breads baked with low and high addition levels were significantly different from each other, making it clear that the more fibre is added, the harder the bread becomes (table 6 and figure 12). The bread baked with the coarse oat hulls had more consistent values between different addition levels than the other breads, which can be interpreted as a lower influence of the proportion of oat hulls added. Remarkably, the hardness of the breads baked with OHF L is comparable to the control.

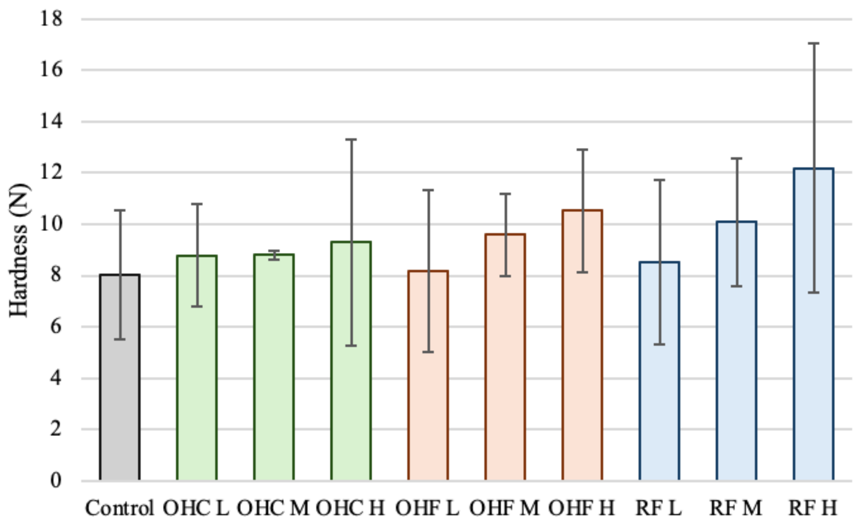

Figure 12. Hardness of breads baked baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels, plus a control bread, measured by texture analysis (TA).

Cohesiveness

Since the cohesiveness of a bread refers to how much pressure it can withstand before cracking, it is a desirable property of a bread (Young 2012). Although there was no significant difference between the raw materials in terms of cohesiveness (table 5 and 6), slightly higher values than the control were found in all breads, except in RF L and OHF L (figure 13). The low addition level was significantly different from the high addition level (table 5 and 6), showing that the trend seems to be that cohesiveness increases with increasing fibre content.

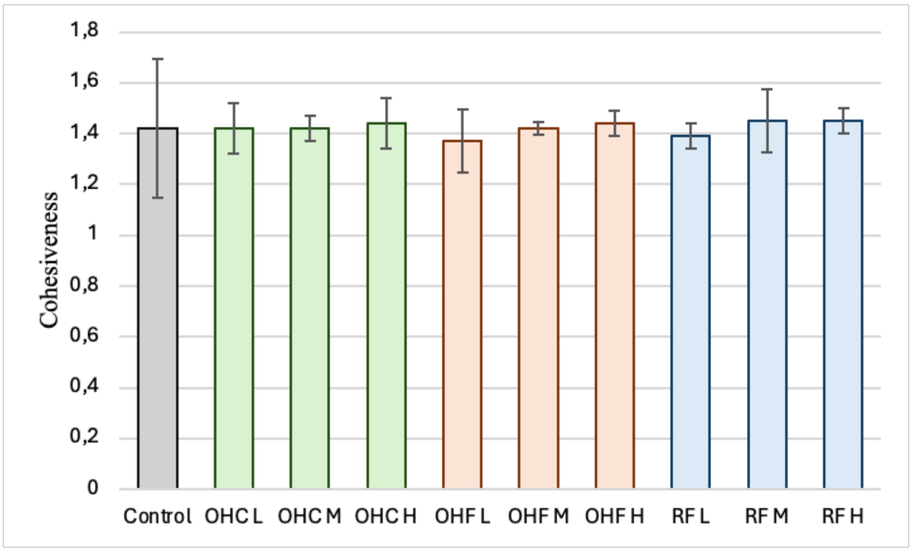

Figure 13. Cohesiveness of breads baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels, plus a control bread, measured by texture analysis (TA).

Springiness

Springiness is also a desired feature of bread as it refers to the ability of a product to return to its original shape after being subjected to pressure (Young et al. 2012). In this project, there was no observed significant difference in the springiness of the breads (table 5 and 6). The values for all samples are strikingly similar, as can be seen in figure 14. Remarkably, however, the control had the lowest measured value. As a high value of springiness is correlated with bread of high quality (Young et al. 2012), these results are interesting. The addition of fibre has, albeit marginally, increased the springiness of the breads.

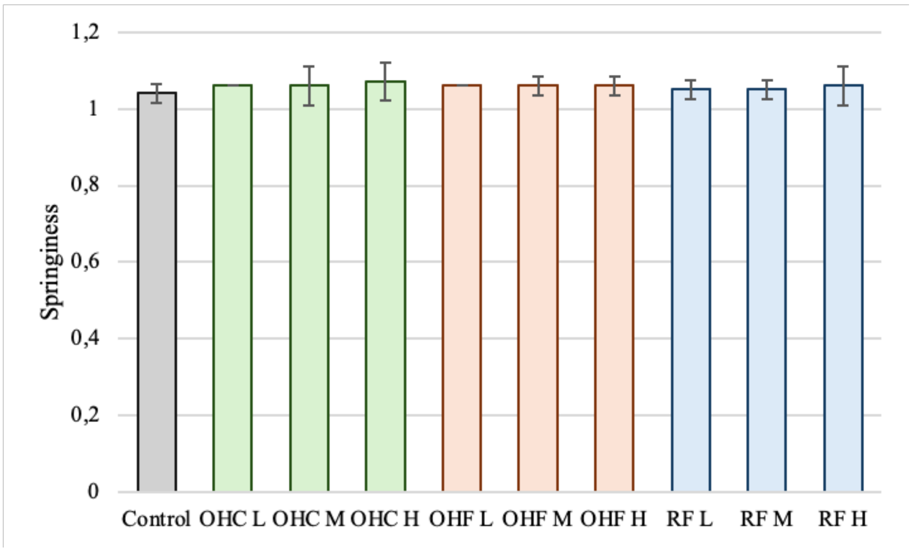

Figure 14. Springiness of breads baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels, plus a control bread, measured by texture analysis (TA).

4.3.4 Image analysis

The crumb structure properties of the samples were obtained by image analysis (see all scanned images in appendix 3). No significant differences were observed between either raw materials or addition levels for the average cell size (table 5). However, in terms of %area, the reference sample differed significantly from both coarsely and finely milled oat hulls (table 6). The fact that the average size of the cells is the same in all breads but the %area of cells is larger in the reference bread signifies that the walls of crumb surrounding the cells are thicker in the breads baked with oat hulls. According to Zghal et al. (2002), thickness of breadcrumb cell walls can be related to differences in cell wall properties. The reasons why cell wall properties may differ can be due either to variations in starch content or to different strain hardening of the protein molecules. If the cell walls are thinner because the starch granules are smaller, this leads to lower mechanical performance. If, on the other hand, the thin cell walls are related to strain hardening in the protein molecules, it results in stronger cell walls and thus a tougher bread (Zghal et al. 2002, Hug-Iten 1999). In this project, the differences are not striking, *i.e* the differences in cell wall properties between breads baked with oat hulls and the reference fibre are too small to draw clear conclusions.

As shown in table 7, the %area and average cell size of the air bubbles in the bread baked with the reference fibre had a trend of decreasing with increasing fibre content. The relationship, though, is not a clear trend for the breads baked with bleached oat hulls.

Table 7. Crumb structure properties of breads baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M) or high (H) levels, plus a control bread, obtained by image analysis

	Average cell size	%Area
Control	33.03±4.75	12.65±2.71
OHC L	35.11±5.88	15.75±3.79
OHC M	40.41±6.59	18.91±3.27
OHC H	38.75±6.03	18.26±2.84
OHF L	38.26±5.06	17.99±0.91
OHF M	35.93±4.09	17.93±1.80
OHF H	39.22±7.86	16.9±3.66
RF L	40.24±2.59	20.57±2.38

RF M	38.25±2.52	18.84±1.68
RF H	35.32±5.94	15.69±1.47

± indicates standard deviation

4.4 Sensory evaluation

To complement the physical analyses, a sensory evaluation was carried out in the form of two triangular taste tests. The results of these tests show that there was no significant difference between the bread baked with the high level of finely milled bleached oat hulls and the bread baked with the high level of the reference fibre at a significance level of 5%. There was also no significant difference between the bread baked with the medium level of finely milled bleached oat hulls and the control bread.

In the test where bread baked with OHF H was compared to bread baked with RF H, 8 out of 20 participants were able to identify the sample that differed. Of these, 6 persons answered yes to the question: "Did you taste any difference between the samples?". Only one of the participants who had identified the outstanding sample commented that they did not like the difference. All other participants wrote either that they liked the difference or that they liked the samples equally. This clearly shows that there was no detectable difference in taste between the bread baked with oat hulls and a bread baked with the reference fibre.

In the other test, the bread baked with OHF M was compared to the control bread. Here, 7 out of 20 participants were able to identify the sample that was different. Remarkably, only 3 of them wrote that they could identify the difference. The other 4 were thereby only good guesses since it was a forced-choice test. These results clearly demonstrate that no taste difference was found between the bread baked with oat hulls and the control bread. Some comments were made that the taste was the same for both breads, but the texture between the two samples differed. As the hardness in the bread baked with OHF M oat hulls was higher than in the control bread (figure 12), this is not a surprising but skilled observation of the participants.

4.5 Additional baking

Specific volume

Figure 15 shows the specific volume of the breads baked with very high (VH) addition level. The bread baked with OHC had the highest value of 3.45 ml/g, making it the largest bread. The bread baked with OHF, and the bread baked with RF had similar values of specific volume (2.92 and 2.95 ml/g). This may be because smaller particles enter more easily and disrupt the protein network, thus lowering the volume of the bread (Albasir et al. 2022). When comparing the breads baked with a high addition level of fibre to the breads baked with a very high addition level of fibre, the breads baked with OHC decreased not as much in specific volume as the breads baked with OHF or RF. Since high volume is desirable in bread, the effect of particle size on volume must be considered when developing a new product.

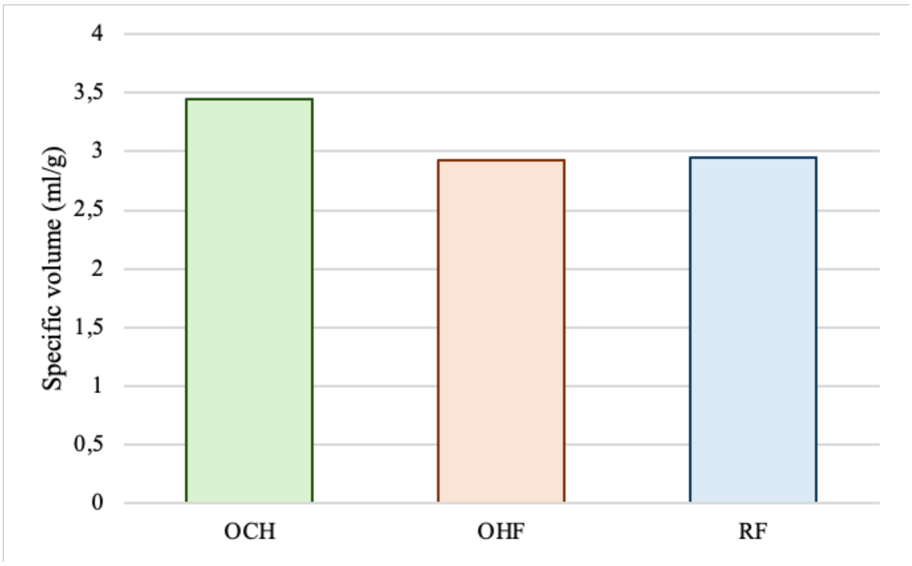

Figure 15. Specific volume of breads baked with a very high (VH) additon level of coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF).

Colour measurement

The lightness of the breadcrumbs is basically the same as it was in the breads baked with high addition level (see figure 9 and table 7) and can be seen in table 8. All breads had also similar a-values as in the breads baked with high addition level. Not surprisingly, the yellowness increased with increasing oat hull addition (table 8), simply because the raw oat hulls had a distinct yellow tone, as stated earlier in the report (table 4). For the reference, the yellowness decreased with increasing fibre content.

Table 8. Colour measurements (L-, a-, b-values) of breads baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF), all with a very high (VH) addition level

	L-value	a-value	b-value
OHC VH	77.45±1.26	0.33±0.11	20.71±0.60
OHF VH	78.31±0.77	0.34±0.15	21.53±0.77

RF VH	77.29±1.85	0.59±0.10	16.86±0.46

± indicates standard deviation

Image analysis

The results from the image analysis are shown in table 9. Interestingly, the bread baked with the addition of OHC VH had the highest values for both average cell size and %area. These results are in accordance with the results of the specific volume. The correlation between the specific volume and the average cell size was high (R=0.9751), indicating that the reason why the bread with the fibre addition of OHC VH had the largest volume was that it also had the largest air bubbles (cells).

Table 9. Crumb structure properties of breads obtained by image analysis. The breads were baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF), all with a very high (VH) addition level

	Average cell size	%Area
OHC VH	32.50±0.87	18.23±1.20
OHF VH	30.91±1.63	12.42±1.83
RF VH	25.23±0.60	15.26±2.24

± indicates standard deviation

5. Conclusion and further research

The purpose of this study was to investigate the effect of bleached oat hulls on bread properties and also to investigate the possibility of using bleached oat hulls as an additive in bread. The bleached oat hulls were compared with a reference fibre used in the food industry. A positive result would be if there is no significant difference between the two and thus allow for a change in the type of fibre supplement in bread production. The effects of the oat hulls and the reference fibre on bread properties were analysed both physically and sensorially.

Firstly, the results from the colour measurements of the raw materials (coarsely milled bleached oat hulls, finely milled bleached oat hulls or reference fibre) showed that milling affects both lightness and colour. The smaller the particles in the material was, the lighter was the colour. Moreover, the yellowness was most evident in the unmilled hulls, and decreased with decreased particle size. Therefore, fine milled oat hulls are preferable in a white bread.

From the results of the bread analyses, it can be concluded that some significant differences were observed in colour and crumb structure, depending on which raw material that was used. For the different levels, *i.e* proportions added, there were significant differences between some samples for colour and texture. This means that the amount of added fibre in terms of oat hull or reference fibre has an impact on the structure of the bread, although the type of fibre is not a determine factor.

Although there were some physically detectable differences between the breads baked with the oat hulls and the reference fibre, the question that needs to be answered is whether these differences are relevant in terms of consumer perception. Does the average bread consumer notice or even care about these differences? According to the sensory analysis carried out in this study, the answer is no, they do not detect the difference. The few participants who noticed a difference did not dislike it. On this basis, there is an opportunity for oat hulls to replace other fibre additives in bread.

Future work should continue to investigate the impact of a higher fibre content on the properties of bread and whether the differences between the two fibre additives become more pronounced. Performing a larger consumer test could then also be of interest.

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Popular science summary

We all need to eat to survive. Producing enough food for the world's population is a major environmental burden. In fact, the food industry is responsible for one third of global greenhouse gas emissions. One way for the food industry to tackle the problem is to become more source efficient. The industry generates a lot of side streams, which are mainly dealt with through incineration. One example of such a side stream is oat hulls.

In Sweden, several thousand tonnes of oats are produced every year. The hulls make up about 30% of the whole oat grain. The hulls are removed because they are not considered human food as they consist mainly of cellulose, which we cannot digest. Oat hulls are extremely high in fibre compared to other cereal hulls, and since the hemicellulose arabinoxylan (known to have various health benefits) accounts for 35% of the dietary fibre content, they are very interesting to use as fibre supplements in food. Oat hulls have not yet been used in any food product, so this would be a groundbreaking step.

In this study, oat hulls were milled into two different flours with different particle sizes and added to wheat bread at three different addition levels. The breads were analysed physically and sensorially and compared with breads baked with a reference fibre (oat bran fibre) used in production today. The results show that the breads baked with the addition of oat hulls had a slightly yellower tone than the breads baked with the reference fibre. The oat hulls also affected the breadcrumbs by making the cell walls slightly thicker. The level of addition affected the yellowness of the breads with added oat hulls. All breads became harder with more added fibre, including the breads with added reference fibre.

The results from the sensory evaluation showed that there was no detectable difference between the breads baked with oat hulls and the breads baked with reference fibre. There was also no detectable difference between breads baked with oat hulls and breads baked without any added fibre. On this basis, there is an opportunity for oat hulls to be used more efficiently, as a fibre supplement in bread.

This project was performed in collaboration with Lantmännen.

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Appendix 1

Table I. Dietary fibre content of the bleached oat hulls.

DF component		Content (% of dm)
Klason lignin		11,68
Insoluble uronic acids		2,13
Soluble uronic acids		0,42
Insoluble sugar residues	rha	n.a.
	fuc	n.a.
	ara	3,45
	xyl	30,55
	man	0,94
	gal	1,18
	glc	31,13
Soluble sugar residues	rha	n.a.
	fuc	n.a.
	ara	n.a.
	xyl	0,09
	man	0,14
	gal	0,03
	glc	0,03
Total DF		81,77

Appendix 2

Table II. Water amounts added to the different doughs baked with different raw materials: coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at different addition levels: low (L), medium (M), high (H)

	Water added (ml)		
Raw material	Low level	Medium level	High level
OHC	131	131	129
OHF	132	131	134
RF	132	133	134

Appendix 3

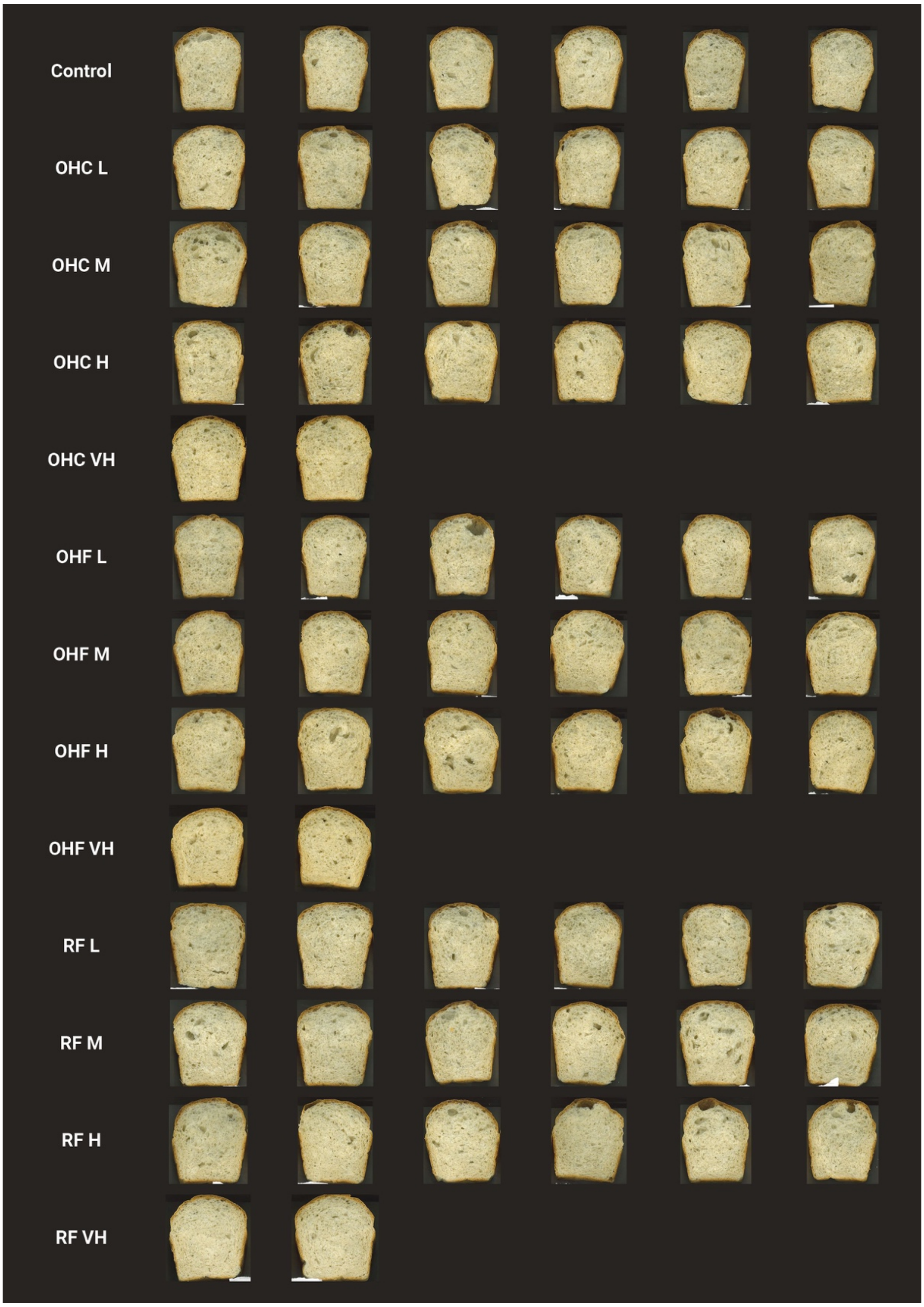

Figure I. Scanned images of breadcrumbs from breads baked with coarsely milled bleached oat hulls (OHC), finely milled bleached oat hulls (OHF) or reference fibre (RF) at low (L), medium (M), high (H) or very high (VH) levels, plus a control bread, obtained by image analysis. All breads were baked in triplicate and two slices from each batch were scanned.

Appendix 4

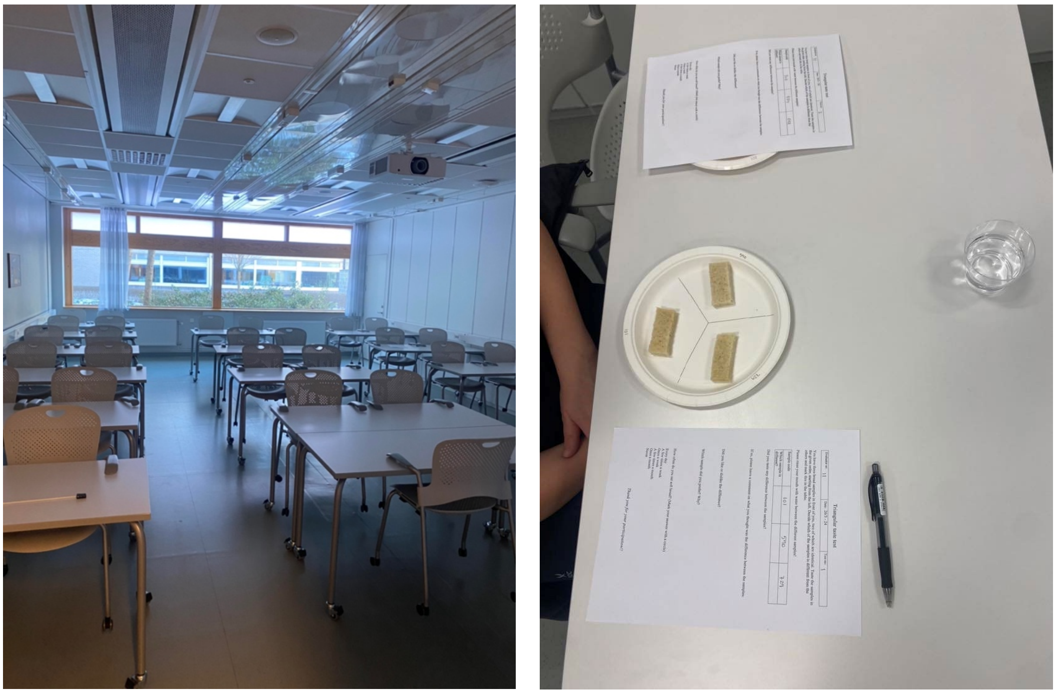

Figure II. Pictures from the sensory evaluation. From left: the room were the evaluation occurred, the served samples and the questionnaire.

Appendix 5

Triangular taste test

Evaluator nr:	Date: 26/3 - 24	Test no:

You have three bread samples in front of you, two of which are identical. Taste the samples in the given order, starting from the left. Decide which of the samples is different from the others and mark this in the table.

Please rinse your mouth with water between the different samples!

Sample code			
Which sample is different?			

Did you taste any difference between the samples?

If so, please leave a comment on what you thought was the difference between the samples:

Did you like or dislike the difference?

Which sample did you prefer? Why?

How often do you eat soft bread? (Mark your answer with a circle)

Every day
A few times a week
Once a week
A few times a month
Once a month
Never

Thank you for your participation!!

Figure III. A copy of the questionnaire used in the sensory evaluation.

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