POATential - The potential of different Oat varieties for Oat drink

REPORT

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PLANT-BASED FOOD GRANT

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Table of content

Conclusion /abstract

The POATential project aimed to investigate how variety and cultivation method affected the quality of oats for oat beverages. Ten varieties were grown under organic and conventional conditions and analyzed for protein and fat content, protein solubility, sensory properties and functional parameters. Due to a challenging growing season, only one organic location was suitable for cultivation, and only two locations were harvested in total. It is therefore not possible to draw unambiguous conclusions regarding cultivation method, as any differences may also be due to other differences between the two locations. However, the results show that genetic characteristics are more important than cultivation method/location in relation to a number of quality characteristics, and that variety selection has an impact on the quality of the oat beverage. However, processing, including in particular heat treatment, was more important than variety selection, as heat treatment affects protein solubility and the formation of volatile components, which affect functional properties and sensory properties.

Varieties with both high fat and protein content have performed best in our testing in terms of foamability. No variety achieves optimal foam stability, but the varieties Sonja, Fatima and Oliehavre perform best.

Sensory analyses showed that the flavor profile of the kernels is to some extent transferred to the oat base, but off-notes arised during storage/processing affected the results. Off-notes presumably arise as a result of several weak Maillard reactions and/or oxidation processes during heat treatment of the oat kernels after dehulling and the subsequent UHT treatments of the oat base.

The project's results support the fact that in the future, specific varieties/quality characteristics and process optimization should be targeted, which can reduce variation in quality and thus strengthen Danish oat beverage production.

Introduction

Plant-based drinks as oatdrink is now a standard offer as an alternative to milk, and Danish oat drink is a climate-friendly choice compared to almond and rice drinks. The food industry is also demanding Danish-produced crops for plant-based foods for the export market, which requires a transformation in agriculture, where 80% of agricultural land is used for feed production.

Oat drink producers face challenges in obtaining raw materials of uniformly good quality, as the functional properties can differ from batch to batch. Until now, there has been no focus on linking specific functional properties in the oat drink with certain quality parameters for different oat varieties or growing conditions.

In the project POATential, we aim to identify key parameters for the raw material and the importance of variety selection. An understanding of variation within oat varieties will enable an optimization of oat drinks and at the same time support the agricultural production of quality oats. Oat cultivation is particularly appealing to organic farmers, as oats are healthy, frugal and competitive against weeds, and contribute to a robust crop rotation.

The purpose of POATential is thus to strengthen primary production of plant-based foods with a focus on oats. The demand for plant-based products creates a unique opportunity to improve raw material quality. The project aims to optimize oat cultivation by identifying the quality of oat varieties with the best for the food industry and investigating whether growing conditions affect the desired quality parameters.

The goal is to provide farmers with the necessary knowledge and incentive to grow quality oats that meet the requirements of the food industry. This is in line with the goal of increasing the volume of Danish plant-based food production and promoting the development of a more sustainable and competitive plant-based food sector.

In the project, different varieties have been selected for cultivation for the production of oat drinks. During the process, functional and sensory analyses of raw materials and oat base are made based on unique variteties.

The project is a collaborative project with the entire process chain represented by the participation of Dragsbæk, Döhler, Valsemøllen, SEGES Innovation, Innovation Center for Organic Agriculture, InnovaConsult and the Danish Technological Institute. The Innovation Center for Organic Agriculture and SEGES Innovation have been responsible for variety selection, planning of cultivation, data analyses of cultivaton data and coordination between the partners. The Danish Technological Institute (Agro) has been responsible for the practical implementation of cultivation and drying, and Valsemøllen for cleaning, dehulling and heat treatment. Döhler has made oat bases and analyses thereof in collaboration with Dragsbæk. InnovaConsult has carried out sensory analyses of seed, harvested grains and oat base. The Danish Technological Institute (Food) has made protein and fat analyses of seed and harvested grains and analysed for volatile components in the oat base.

Innovation Centre for Organic Farming

SEGES INNOVATION

DÖHLER

VALSEMØLLEN SIDEN 1899

Dragsbæk

DANISH TECHNOLOGICAL INSTITUTE

InnovaConsult

Materials and methods

Timeline

Figure 1 shows an overall timeline of the grain's journey from seed to oat base, and the various treatments and processes it has undergone, which are described in this report.

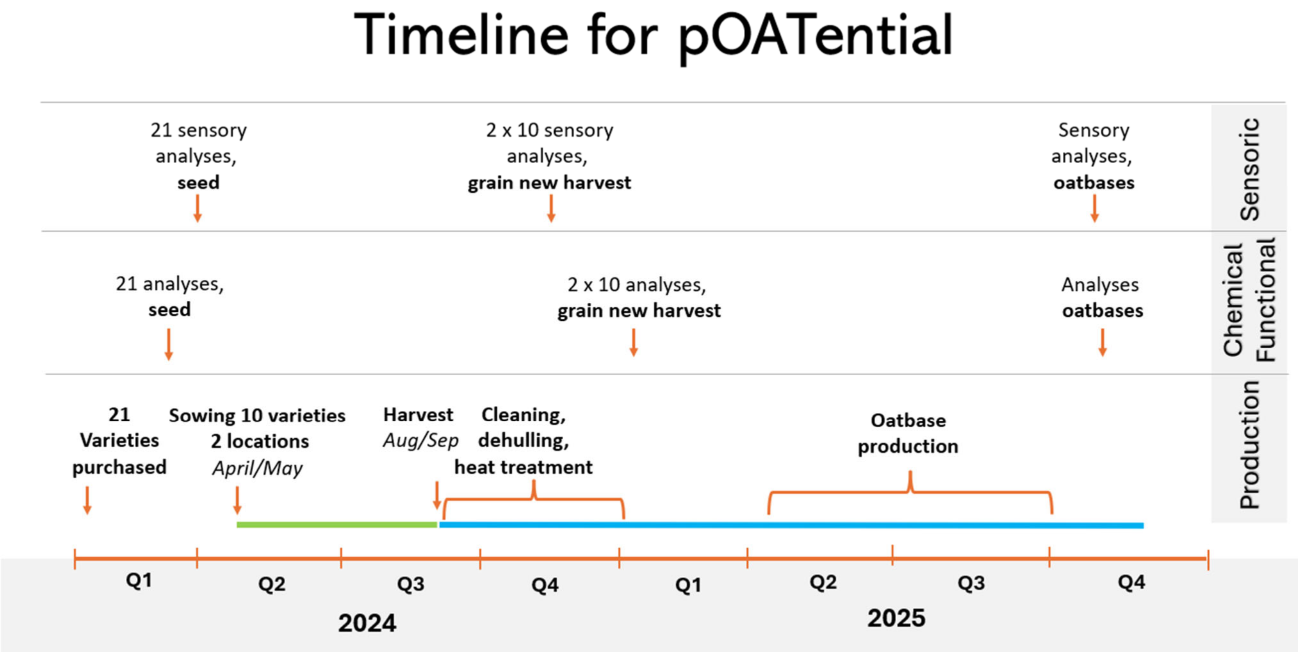


Figure 1. Timeline for production, analysis and sensory evaluation

Variety selection

A very challenging growing season in 2023 resulted in a widespread shortage of oat seed for the 2024 season, and ordering of seed was accelerated to the beginning of January 2024. 21 varieties were selected for analysis of, among other things, fat and protein content. Of the 21 varieties, 10 were selected for cultivation and further processing. There have been various considerations before selecting varieties. Criteria for variety selection were that the varieties should come from several different breeders and with different genetic origins and from both conventional, organic and biodynamic breeding programs. Breeders were contacted to get their recommendations for varieties both in terms of cultivation and quality characteristics. But in addition, there has been a focus on diversity in the varieties. Both well-known and unknown varieties have been selected in terms of groat production. And common varieties with husks and varieties of naked oats without husks have been selected. In addition, varieties with high and low fat, protein and beta-glucan content have been selected. There has also been emphasis on selecting varieties with and without resistance to oat cyst nematodes (an important criterion for frequent cultivation of oats, which is especially seen in organic cultivation). And varieties that are high-yielding and others that give lower yields but possess other interesting properties.

Growing conditions

It was not possible to sow the conventional plots until April 30 and the organic plots until May 3, which is late for oats. Photo: Michael Erlang-Nielsen, Danish Technological Institute.

The varieties have been grown under both organic and conventional growing conditions. In addition to whether the growing has been organic or conventional, there are also other factors that can affect the quality of the harvested product - this can be soil type, management, weed control, fertilizer level etc. The results can only give an indication of whether there are differences in quality parameters based on cultivation/location. Further cultivation trials are needed to be able to conclude whether any differences between oats grown at the different locations are due to organic/conventional growing conditions, or whether there are other factors that play a role. This will require a more extensive experimental setup.

The cultivation plots were laid out randomly, to take into account any variation in the field. Geographically, both the conventional and the organic location were located on Djursland. The conventional plots were laid out on JB 6 soil and cultivated according to general conventional practice, like the surrounding field. The organic plots were laid out on JB 3 soil and fertilized in connection with seedbed preparation, like the surrounding field. The spring of 2024 was very challenging with high rainfall, and it was difficult to find suitable cultivation areas, as many areas were under water and potential cultivation areas had to be discarded. This also meant that sowing was relatively late for oats, which are normally sensitive to late sowing.

In the organic plots, ploughing and fertilising with Øgro was carried out before sowing. Sowing was carried out on 3 May with a seed quantity calculated based on sowing 400 germinating plants per square metre. In the conventional plots, manure was applied before ploughing and harrowed before sowing. Here, sowing was carried out on 30 April with a seed quantity calculated based on sowing 350 germinating plants per square metre. Field germination percentage was estimated at 85% of the seed germination in the laboratory.

The organic plots were harvested on 20 August and 3 September (only a small part of Talkito and oil oats were harvested on 3 September, to ensure sufficient quantity), the conventional plots were harvested on 28 + 29 August. Harvesting was done with an experimental combine harvester, with extra focus on cleaning the machinery between the harvest plots to avoid mixing varieties.

Harvesting with an experimental combine harvester. Photo: Michael Erlang-Nielsen, Danish Technological Institute.

For each variety, seed from the same batch was used at the different locations. The seed was ordered from a number of different countries, where it was grown under very different cultivation and climatic conditions, and was stored under varying storage conditions and for different durations. The analysis results of the purchased seed of the 21 varieties are therefore not only an expression of varietal differences but also reflect the above conditions. However, the analyses give an indication of the properties of the different varieties, and the ten varieties that have been selected for cultivation will no longer have this bias after cultivation at the same location and after the same drying and storage, as the cultivation conditions and storage for these will be the same.

No experimental measurements of yields have been made in the experiments, but an estimate of yields has been made by weighing the harvested yield.

Drying

The Technological Institute was responsible for harvesting and drying the grain. The grain was harvested directly into 20 kg canvas sacks. The oats were harvested relatively dry with a moisture content of approximately 14%. Immediately after harvest, the sacks of oats were placed on flat storage and dried with cold air for approximately 3 days to ensure that any water-containing weed seeds did not give rise to “wet pockets” that could cause mold and heat generation in the harvested crop. After drying, the oats were stored dry and cool before being shipped to Valsemøllen. The moisture content upon arrival at Valsemøllen was measured to be between 13 and 14.9% using FOSS infra-tec equipment.

The grain was harvested directly into 20 kg canvas sacks. Photo: Michael Erlang-Nielsen, Danish Technological Institute.

Cleaning, dehulling and heating

After drying, a cleaning process was carried out at Valsemøllen. Straw, impurities and kernels under 2 mm were removed before dehulling.

The ability of the oat kernels to be dehulled and the proportion of hulls are important properties when oats are to be used for human consumption. To determine the hull proportion and the proportion of dehulled kernels (weight percentage), a laboratory dehulling of 50 g of raw material was carried out for 1.5 min at 5 Bar air pressure at Valsemøllen. The individual fractions were weighed. A dehulling percentage of 95% therefore means that 5% of the kernels (weight) still have the hull after the dehulling process. The hull proportion is calculated as the difference in weight before and after dehulling as a percentage of the weight before dehulling.

The batches for further processing were dehulled with Valsemøllens standard procedure.

To slow down enzymatic oxidation processes, the grain has been steam-treated at temperatures up to almost 85 degrees for approximately 45 minutes, after which it has been heat-dried for a similar length of time. The time for heat treatment has been determined after testing for lipase and peroxidase activity. A test for lipase- and peroxidase activity has been performed after heat treatment to ensure inactivation of the enzymes, which can cause oxidation of fat in the oat. The test used are OAT-CHECK I and OAT CHECK II from LSB Products.

Production of oat base

The raw material has been tested for peroxidase activity at Döhler using Peroxidase Test MQuant from MERCK and Peroxtesmo KO peroxidase test paper from Macherey-Nagel. Free fatty acids have

been measured with LC-MS method. Döhler has a wide range of commercially available oat bases/oat syrups and regularly processes oats in their factories. A first pilot test series was conducted based on 50 kg of raw material of all varieties, and a second test on five selected varieties. The process chosen for the project begins with wet-grinding the raw material with water. Hydrolysis has been carried out using enzymes, where amylases break down the starch into smaller fragments. Beta-glucanases are needed to further break down the viscosity during processing. After the hydrolysis, an extraction has been carried out, where insoluble components have been removed by centrifugation and decantation. Finally, concentration and preservation by UHT at 141 degrees for 30 seconds have been applied in order to make the oat base more shelf life stable.
The oat base has then been analysed for a number of parameters with NIR analyses; dry matter content and fat and protein content. And Performance tests have been carried out with a test of foamability and an evaluation of the extract in terms of colour and sensory properties.

Sensory analyses

Sensory analyses were carried out by InnovaConsult. This is not a broad taste panel, but a single "supertaster" who is an expert in sensory analysis. The seed and the harvested kernels were dehulled before the sensory test. The seed was dehulled by hand and the harvested kernels were dehulled with laboratory equipment. The sensory test was carried out as a blind test with a description of a number of descriptors for taste, aroma, consistency and mouthfeel. Humans can detect the five basic tastes with their tongue (salty, sour, sweet, bitter, umami) and together with the sense of smell and mouthfeel, around 10,000 different tastes can be registered. 242 flavours and aromas have been identified in oats, of which there are around 194 descriptors. In comparison, milk cream has 70 flavours and aromas, of which 39 are common with oats, and therefore oats can have flavour notes of, among other things, milk cream. It is based on these different descriptors that an objective assessment of the individual varieties has been made from both organic and conventionally grown samples.

Test category	**Treatment before sensory evaluation**
Seed (21 varieties)	No heat treatment. Manually dehulled before testing.
Harvested grain (10 varieties)	No heat treatment. Dehulled in laboratory equiptment; sensory test before heat treatment.
Oat base (selected varieties)	Before UHT-treatment
Oat base (selected varieties)	After UHT-treatment

Protein content

The Danish Technological Institute has carried out analyses of protein in the seed and the harvested grain. The analyses of the seed were carried out with the hulled kernels. Analyses of the harvested product were carried out after dehulling and heat treatment.

Protein content was measured as a percentage of raw material and as a percentage of dry weight.

Protein content was also measured at Döhler using NIR.

Protein analyses (proteomics) – distribution of important proteins

A quantification of key proteins in both seed and harvested kernels has been made. The proteins examined are (based on literature/expert experience):

- Albumins, important for foamability, water holding capacity ((WHC) and fat binding capacity (FBC).
- Glutelins, important for emulsion activity index (ESI).
- Prolamins, important both in relation to emulsion activity index and long-term foam stability.
- Globulins, which are more significant when it comes to short-term foam stability.

The proteins are separated using SDS-PAGE electrophoresis, where the proteins migrate on a gel, which is stained with Coomassie blue, to identify the individual bands. Protein samples from the gel are proteolyzed into shorter peptides and using mass spectrometry, the peptides are identified, and the peptide sequences are found using a protein sequence database and from this the proteins are identified.

Protein solubility

Protein solubility is highly dependent on pH. At the isoelectric point, where proteins have a neutral net charge, they are least soluble. The isoelectric point for albumins is at pH 4.0-7.5, for globulins it is approximately 5, and for prolamins it is 5.0-9.0. The effect of different pH values (4.5; 6.5 and 8.5) on protein solubility has been measured on oat samples, and protein solubility at ambient temperature has also been measured at different concentrations of NaCl (0.0; 0.1 and 0.5) at the three different pH values. The protein content has been measured using the Dumas method (Nx6.25). Heat treatment usually reduces protein solubility by about 50%, which is due to the denaturing of proteins, while albumin and prolamin aggregate at high temperatures.

Fat analyses

As for protein content, the Danish Technological Institute has carried out fat analyses of the seed and the harvested kernels. The analyses of the seed were made with the dehulled kernels. Analyses of the harvested product were made after dehulling and heat treatment.

The content of non-polar fat was measured. It has previously been shown that by removing non-polar fat there is improved foaming and increased emulsion stability. Non-polar fat in oats affects the solubility of proteins. The total fat content was measured using the Bligh and Dyer principle, which is a two-step extraction with chloroform, methanol and water. Non-polar fat content is extracted with 90:10 P-ether/diethyether (P/D), and the polar fat is extracted with diethylether (D).

Fat content was measured at Döhler using NIR as a percentage of dry matter.

Foam stability and bubbles

The planned analysis of foam formation and stability at the Danish Technological Institute has not been completed. Foam formation and stability were to be measured using Turbiscan, and bubble size and “draining” using electron microscopy or the like – but due to challenges with the raw material, the Danish Technological Institute has instead made analyses for volatile components in the oat base. Foam testing of the oat bases has been carried out by Döhler.

An oat drink is expected to be able to deliver a high degree of foam volume regardless of whether it is enjoyed chilled, at ambient temperature or heated. Therefore, the oat base is tested at both low and high temperatures. It is easiest to identify a candidate with poor foamability at low temperatures, as a candidate with poor foamability can perform well at high temperatures. Therefore, both measurements are important to have a complete picture of the foam quality.

The principle behind the method is to produce a mixture of oat syrup, rapeseed oil, deionized water and calcium carbonate, basically an oat drink on a laboratory scale. The addition of calcium carbonate is chosen to challenge the foaming properties of the matrix, where together with a poor foamer an unstable emulsion is formed. A Turrax is used at low speed. In addition, the foaming properties are challenged by pasteurization at 95 °C with subsequent incubation in an ice bath and overnight storage in the refrigerator. In a typical oat drink, the protein to fat ratio is around 1:3. This ratio is used in the mixture for the test.

Using a conventional foaming device (GRAEF milk frother), 200 ml of the oat drink is foamed on a laboratory scale. A poor foamer is identified when the foam volume is less than 250 ml, a medium foamer is between 250 ml and 305 ml, and a good foamer is above 305 ml. However, this device is susceptible to malfunctions when used daily in the laboratory. To make hot frothing more robust, a preheating step using a water bath was introduced.

Volatile components in oat base

Volatile components from the oat base have been analyzed using Static headspace GC (coupled with FID and MS detector). Here, the gas phase is analyzed from a closed glass after an equilibrium state has been reached between substance and gas phase (=headspace). The gas is analyzed using mass spectrometry and GC "peaks" are identified. The higher a peak, the higher the concentration of the volatile component. The NIST database (NIST 2020) has been used to identify the individual components. The area of the individual peak has been used to determine the concentration of the individual component.

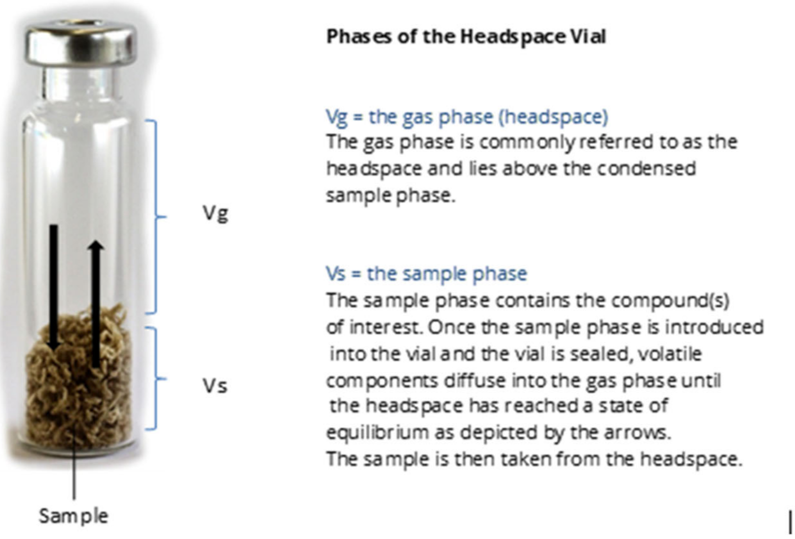


Figure 2. Illustration of phases in the headspace vial. From Danish Technological Institute.

Analyses have been made on conventionally grown Scotty, Sonja, Active, NOS Conrad and Oliehavre as well as organically grown Oliehavre.

Results, seed

Oat varieties

The selected oat varieties originate from breeders in England, Germany, Finland, Sweden, Austria, France, the Netherlands and Denmark and are expected to have different functional and sensory properties. Nemesis, Dominik and NOS Conrad are nematode-resistant varieties according to the Danish descriptive variety list. Talkito and Austrian bitter oats are naked oats. The breeders state that Oliehavre has very high fat content and Active a high beta-glycan content. Fatima is a variety known for its high fat and protein content. Sonja is a new Finnish variety, which the breeder recommends for oat drinks. See selected characteristics in Tables 1 and 2.

Table 1. Oat varieties for cultivation and analysis, selected characteristics

Oat variety	Breeder	Characteristics and country of origin
Scotty	Nordsaat	Known variety for groats production at Valsemøllen, Germany
Fatima	Svalöv/Lantmännen	High fat content (Danish trials 2016), Sweden
Sonja	Boreal	New variety, recommended for oat drink by breeders, Finland
Active	Svalöv/Lantmännen	Variety with high beta-glucan content, Sweden
Merlin	Selgen	Variety that can handle a lot of rainfall, UK
Elison	Edelhof	Sold in DK, tested in organic Danish trials, Austria
Nemesis	Svalöv/Lantmännen	Nematode resistant variety, Sweden
NOS Conrad	Nordic Seed	New variety with nematode resistance, Denmark/Germany
Oliehavre	Landsorten	Organic variety with high fat content, Denmark
Talkito	Cultivari	Naked oats from biodynamic breeding, Germany

Table 2. Additional oat varieties for analysis (no cultivation), selected characteristics

Oat variety	Breeder	Characteristics and country of origin
Dominik	Saatzucht B. Bauer	Known variety (nematode resistant) for groats production at Valse-møllen, Germany
Aust. bitter oat	Landsorten	Naked oat from Landsorten, Austria
Symphony	Nordsaat	Known variety for groats production at Valsemøllen, Germany
Caddy	Nordsaat	Widespread variety in Denmark, Germany
Lion	Nordsaat	Known variety for groats production at Valsemøllen, Germany
Talkunar	Cultivari	Biodynamic variety, naked oats with large kernels, Germany
NOS 81962-12	Nordic Seed	New variety, Denmark/Germany
RGT Skara	RAGT	New variety, France
Dådyrhavre	Landrace	Landrace grown in Denmark
WPB Oscar	Wiersum	Widespread variety in Denmark, Netherlands
Kaspero	Dottenfelderhof	Biodynamic variety, good dehulling ability, Germany

Seed analyses – dehulling

There has been a large variation in the proportion of hulls and the proportion of hulled kernels for the individual varieties during laboratory hulling, see table 3. The highest proportion of hulls was measured in Kaspero with 33.3%, followed by Nemesis with 30.6%. The lowest proportion of hulls was found in Symphony and Elison with 18.6 and 18.7%, respectively. When calculating the proportion of hulls, kernels that have not been hulled are not included. The proportion of hulled kernels varies from 98.8% in Symphony to 63.8% in RGT Skara.

Table 3. Laboratory dehulling (seed)

Oat varieties	Dehulling	
	Hull in raw material, %	Dehulled kernels, %
Scotty	25,3	94,2
Fatima	23,2	91,0
Sonja	26,1	78,5
Active	21,8	91,9
Merlin	21,2	94,9
Elison	18,7	70,6
Nemesis	30,6	97,1
NOS Conrad	25,6	85,8
Oliehavre	25,4	97,9
Talkito (nøgen)	-	-
Dominik	20,2	80,7
Austrian bitter oat (naked)	-	-
Symphony	18,6	98,8
Caddy	23,5	92,7
Lion	25,2	96,6
Talkunar (naked)	-	-
NOS 81962-12	29,6	87,2
RGT Skara	25,6	63,8
Dådyrhavre	26,6	89,7
WBP Oscar	29,7	85,2
Kaspero	33,3	78,7

Sensory analyses of seed

In the sensory test of the seed, 30 taste and aroma descriptors and 15 texture and mouthfeel descriptors were found.

The 30 taste and aroma descriptors are: Bitter, bread, fat, cream, bird grass, green, rancid, oat, oatmeal, hay, intense, earthy, bran, grain, hay loft, grain dust, cellar note, corn treads, elm manna, flour, mild, nutty, off-note, oxidized, clean (no off-notes), sharp, sour, sweet, wet hay.

The 15 texture and mouthfeel descriptors are: Soft, elastic, firm, solid residual pieces, smooth (surface), glutenous, hard, sticky, scratchy-in-the-throat, floury, floury surface, rough surface, sandy, slimy (like oatmeal), dry (surface).

Sensory data for each variety (seed) is only available in Danish version.

There is obvious visual diversity in the 21 oat varieties (seed) – seen here with hulls. The hull proportion has varied from 18.6-33.3 percent. Photos: Karin Loft Eybye, Danish Technological Institute.

During the test, the samples of the individual oat varieties were anonymized to avoid bias. Photo: Lisbeth Ankersen, InnovaConsult

Protein content in seed

Table 4 shows that the protein content in the kernels varies between 8.1g in Scotty and 15.1g in Active out of 100g of oats. The corresponding values of the dry weight are between 9.2 and 17.0g per 100g dry weight. Figure 3 shows the protein content in dry matter.

Table 4. Protein content in seed

	% protein (g/100 g oat) Mean and standard deviation	% protein (g/100 g DM) Mean and standard deviation
Scotty	8,1 ± 0,1	9,2 ± 0,2
Fatima	12,6 ± 0,2	14,1 ± 0,2
Sonja	11,4 ± 0,2	12,6 ± 0,2
Active	15,1 ± 0,3	17,0 ± 0,4
Merlin	12,3 ± 0,2	13,8 ± 0,2
Elison	10,0 ± 0,7	11,3 ± 0,8
Nemisis	12,1 ± 0,0	13,6 ± 0,0
NOS Conrad	11,6 ± 0,2	13,0 ± 0,2
Oliehavre	11,1 ± 0,0	12,8 ± 0,1
Talkito	11,9 ± 0,0	13,6 ± 0,1
Dominik	11,2 ± 0,1	12,9 ± 0,1
Austrian bitteroat	12,4 ± 0,1	14,9 ± 0,1
Symphony	9,5 ± 0,3	10,9 ± 0,3
Caddy	9,6 ± 0,4	11,0 ± 0,5
Lion	9,4 ± 0,2	10,7 ± 0,2
Talkunar	13,4 ± 0,0	15,2 ± 0,0
NOS 81962-12	11,4 ± 0,3	13,0 ± 0,4
RGT Skara	12,8 ± 0,1	14,6 ± 0,1
Dådyrhavre	9,5 ± 0,2	11,0 ± 0,2
WBP Oscar	10,5 ± 0,3	11,9 ± 0,4
Kaspero	11,8 ± 0,0	13,4 ± 0,0

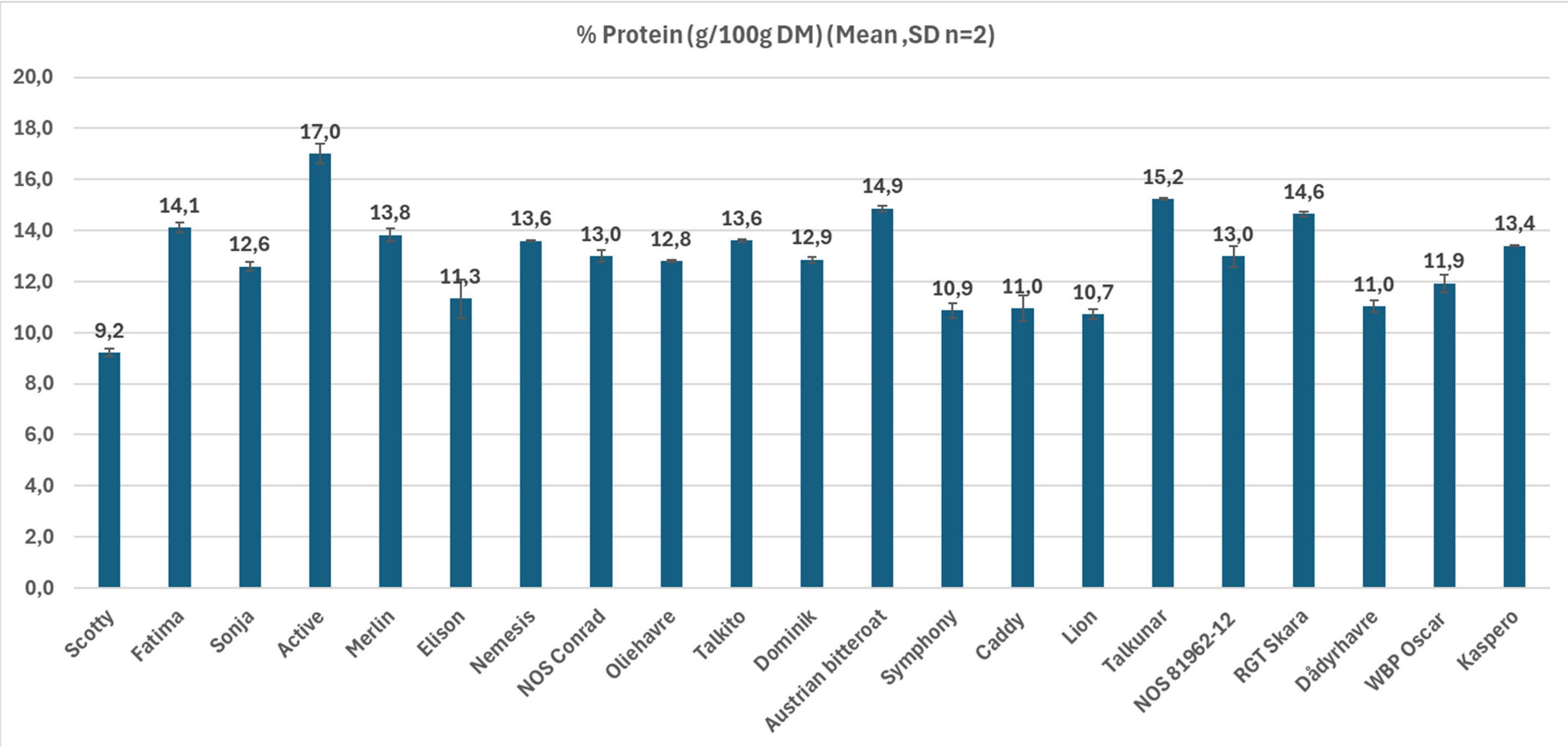


Figure 3: Protein content, % of dry matter in 21 oat varieties (seed).

Protein analyses (proteomics) – distribution of important proteins in seed

Table 5 shows the percentage distribution of the four main types of protein – namely prolamin, globulin, albumin and glutelin. Prolamin constitutes between 11 percent in Kaspero and 23 percent in Scotty of the total protein. α-Globulin constitutes between 36 percent in Lion and 44 percent in Austrian bitter oat, and β-Globulin constitutes between 28 percent in Active and 37 percent in Lion. Glutelin constitutes between 4 and 6 percent with several varieties at the same level. Albumin constitutes between 5 percent in RGT Skara and Dådyrhavre to 10 percent in Caddy. In conclusion there is variation in the protein distribution between the main groups of proteins.

Table 5. Protein distribution in kernels of 21 oat varieties (seed)

% distribution	Prolamin	α-Globulin	β-Globulin	Glutelin	Albumin
Scotty	23	37	29	4	8
Fatima	14	43	32	5	6
Sonja	15	41	32	5	7
Active	19	40	28	5	8
Merlin	15	38	33	6	9
Elison	14	39	33	6	8
Nemisis	13	41	33	6	7
NOS Conrad	16	39	32	6	7
Oliehavre	15	39	34	5	7
Talkito	16	40	32	5	7
Dominik	16	39	34	5	7
Austrian bit-teroat	15	44	34	4	3
Symphony	15	39	31	5	9
Caddy	15	37	32	5	10
Lion	14	36	37	5	8
Talkunar	18	38	32	5	7
NOS 81962-12	13	43	33	6	6
RGT Skara	15	41	36	4	5
Dådyrhavre	17	40	34	4	5
WBP Oscar	16	40	33	5	6
Kaspero	11	39	37	6	7

Figure 4 shows a graphical representation of the variation in protein distribution between the varieties.

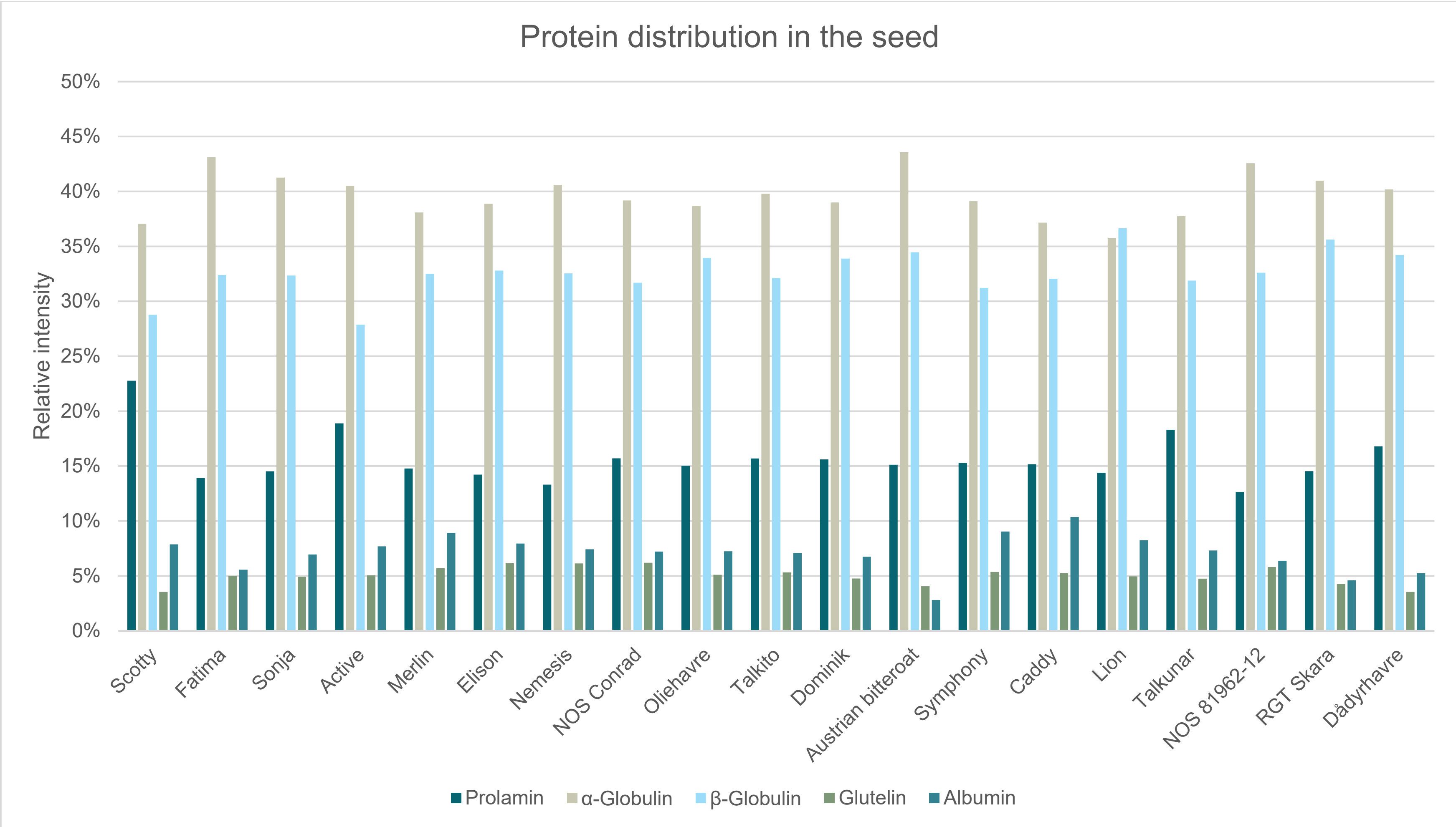


Figure 4. Protein distribution in 21 oat varieties (seed).

Protein solubility at different pH-values and salt concentrations in seed

Table 6 shows the average protein solubility at three different pH values and three different salt concentrations. Red color indicates lower solubility with increased color intensity, and green color indicates higher protein solubility with increased color intensity.

Table 6. Values show average percent soluble protein in oat varieties (seed) at pH 4.5, pH 7.5, and pH 8.5, at three salt concentrations.

	pH 4,5			pH 7,5			pH 8,5		
	0 % NaCl	0.1 % NaCl	0.5 % NaCl	0 % NaCl	0.1 % NaCl	0.5 % NaCl	0 % NaCl	0.1 % NaCl	0.5 % NaCl
Scotty	14,3	14,1	16,2	18,1	18,8	19,4	24,4	24,1	24,3
Fatima	12,9	13,1	14,3	17,1	17,0	15,9	21,9	22,5	20,7
Sonja	16,2	15,7	17,5	18,8	20,2	20,8	25,1	23,5	24,9
Active	11,9	11,6	13,0	14,3	15,7	16,2	19,7	20,0	19,5
Merlin	13,2	12,7	14,1	15,8	16,8	16,4	20,1	19,8	18,6
Elison	13,1	13,5	14,7	16,6	17,7	17,8	22,8	21,8	20,7
Nemesis	12,9	12,8	14,3	17,3	17,8	19,4	23,1	22,3	23,1
NOS Conrad	11,6	11,6	13,1	15,3	15,6	17,0	19,6	19,7	20,4
Oliehavre	11,1	11,1	12,0	13,4	15,6	16,1	18,0	15,9	16,2
Talkito	11,6	12,2	13,7	15,4	14,6	15,8	18,6	18,2	17,4
Dominik	11,4	10,6	12,1	15,3	15,2	15,4	21,9	21,2	22,5
Austrian Bitter oat	12,9	12,7	14,2	15,3	15,7	15,7	19,9	19,4	19,9
Symphony	13,1	13,3	15,1	16,9	17,5	19,1	23,6	23,9	25,3
Caddy	12,5	13,1	13,6	16,5	16,6	17,8	23,7	22,9	23,8
Lion	14,2	13,2	15,3	17,8	18,6	19,0	24,9	24,9	24,7
Talkunar	13,6	13,5	15,2	16,5	17,7	18,2	21,7	20,7	20,8
NOS 81962-12	12,2	11,9	13,4	17,3	16,6	18,0	20,9	20,4	20,8
RGT Skara	9,5	9,6	10,7	12,7	13,6	14,0	19,1	18,2	19,5
Dådyrhavre	13,7	13,9	15,3	17,7	17,8	18,6	22,7	21,1	21,6
WBP Oscar	14,1	14,3	15,7	17,6	19,1	19,4	26,4	26,1	27,6
Kaspero	12,3	12,3	13,2	14,6	16,0	15,8	19,3	17,5	17,5

In Table 6 it shows that, for example, there is low protein solubility in the variety RGT Skara, especially at low pH. And high protein solubility is seen, for example, in the varieties WBP Oscar, Lion and Sonja. At low pH, protein solubility appears to increase with increasing salt concentration.

Fat content and unpolar fat in the seed

The analyses were performed on seed with hull, which is important to be aware of when both varieties with and without hull (naked oats) are included. The fat percentage was highest in Fatima and Oliehavre and Talkunar, and lowest in Kaspero, Dådyrhavre, NOS 81962-12 and Sonja. The proportion of non-polar fat out of the total fat amount was highest in Nemesis and Fatima and significantly lower in Sonja. The proportion of non-polar fat out of the total weight of the kernel is highest in Fatima followed by Oliehavre and Talkunar. The lowest proportion of non-polar fat in Sonja. See table 7 and figure 5.

Table 7. Fat content and proportion of non-polar fat in oat kernels (seed with hull)

	% fat in kernel (g/100g)	% unpolar fat (g/100 g)	g unpolar fat/100 g kernel
Scotty	4,6 ± 0,0	60,1 ± 0,3	2,8 ± 0,0
Fatima	7,7 ± 0,4	65,5 ± 1,8	5,0 ± 0,1
Sonja	3,8 ± 0,1	46,0 ± 0,4	1,7 ± 0,0
Active	5,0 ± 0,1	56,8 ± 1,1	2,9 ± 0,1
Merlin	4,3 ± 0,0	56,9 ± 0,5	2,4 ± 0,0
Elison	4,1 ± 0,7	57,4 ± 1,4	2,4 ± 0,1
Nemesis	4,3 ± 0,1	66,3 ± 0,0	2,9 ± 0,0
NOS Conrad	4,5 ± 0,0	59,5 ± 0,3	2,7 ± 0,0
Oliehavre	7,0 ± 0,3	64,3 ± 2,5	4,5 ± 0,2
Talkito	5,9 ± 0,1	63,4 ± 1,3	3,7 ± 0,1
Dominik	5,3 ± 0,5	60,4 ± 5,1	3,2 ± 0,3
Austrian bitteroat	4,9 ± 0,0	58,9 ± 1,2	2,9 ± 0,1
Symphony	4,0 ± 0,1	54,9 ± 0,2	2,2 ± 0,0
Caddy	4,5 ± 0,1	62,1 ± 0,4	2,8 ± 0,0
Lion	4,4 ± 0,1	56,4 ± 1,0	2,5 ± 0,1
Talkunar	6,8 ± 0,2	62,2 ± 5,5	4,2 ± 0,4
NOS 81962-12	3,8 ± 0,1	60,0 ± 0,9	2,3 ± 0,0
RGT Skara	4,2 ± 0,1	56,2 ± 1,2	2,3 ± 0,1
Dådyrhavre	3,8 ± 0,2	52,7 ± 0,4	2,0 ± 0,0
WBP Oscar	4,4 ± 0,1	54,0 ± 2,1	2,4 ± 0,1
Kaspero	3,7 ± 0,4	56,9 ± 2,9	2,1 ± 0,1

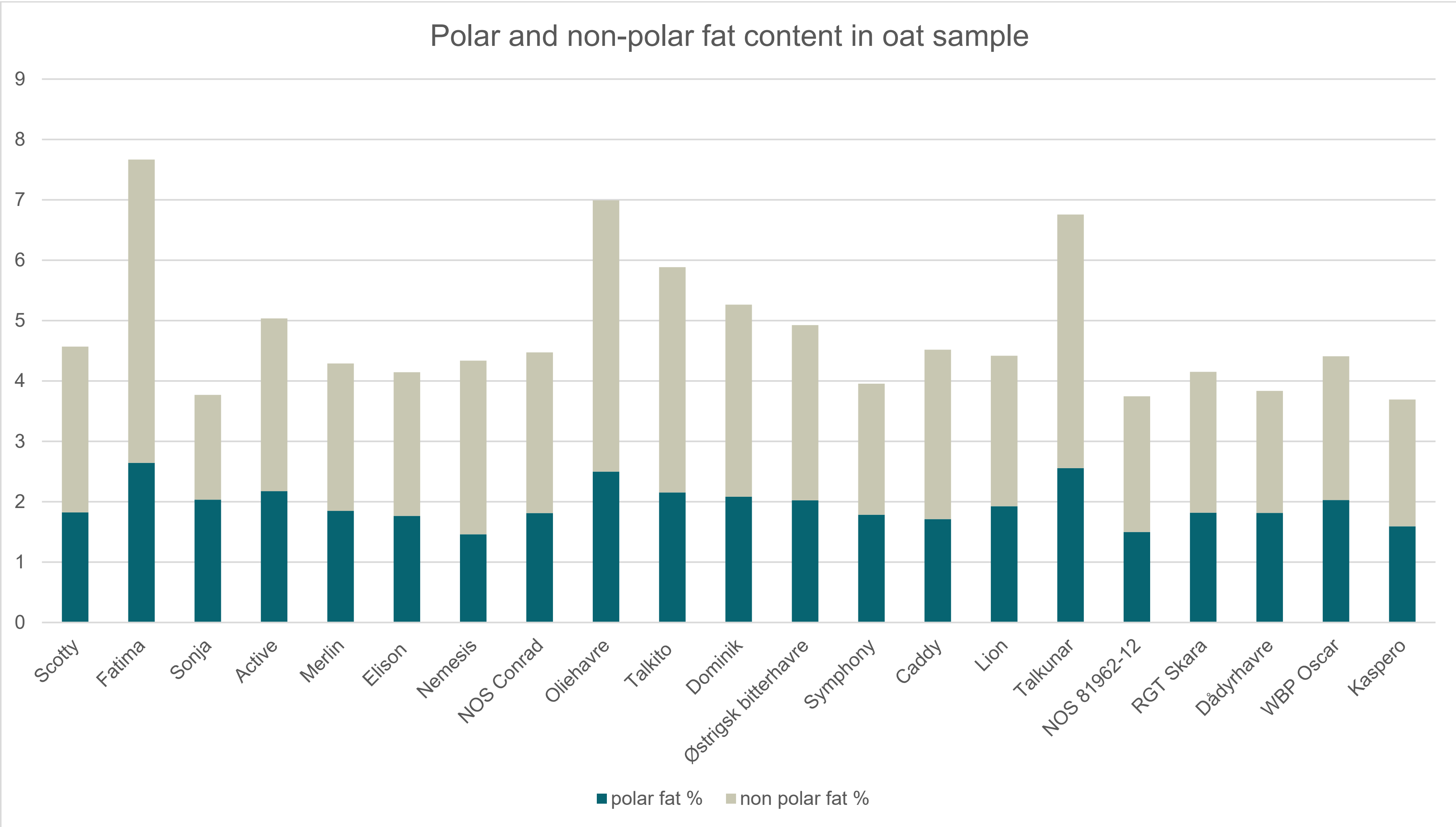


Figure 5. Fat content in oat varieties (seed). The sum of the bars is the fat percentage in the oat sample, and the light part of the bar is the proportion of the fat percentage that is non-polar fat.

The initial analyses of the seed were done on kernels with hull. Photo: Karin Loft Eybye, Danish Technological Institute

Results, harvested grains

Below samples from organic location is named Ø and conventional location K.

Cultivation results and quality parameters in harvested grains

Ten oat varieties have been grown as raw material for oat drink under conventional and organic growing conditions, respectively. Cultivation characteristics and diseases have been recorded during the growing season. No diseases have been assessed after 31 May.

The fertilizer ØGRO was added to the organic plots before the establishment of experimental plots. Photo: Michael Erlang-Nielsen, Danish Technological Institute.

Organic cultivation plots

During harvesting, the harvested amount of grain was weighed, and an estimated yield of between 15 and 47 hkg per ha was obtained for the different varieties, but since this is not a yield trial, yields for the individual varieties are not shown in the report. The low organic yields are probably due to the late sowing date and partly due to the low level of fertilizer and competition from weeds in plots with a low number of plants.

In some of the varieties, germination has been very low, and when calculating the seed quantity, an attempt has been made to compensate by increasing the seed quantity accordingly. The hulls of naked oats fall off during threshing, and this makes the grains more sensitive to mechanical impact and fungal attack, which may explain the low germination observed in naked oats.

In the naked oat Talkito, there has been a low plant population and a very high weed cover of 88 percent on May 31. In the other varieties, weed cover varied between 26 and 36 percent on May 31, and there was normal germination.

Fatima and Oliehavre are the tallest varieties with a straw length of 101 and 102 cm respectively. Talkito and NOS Conrad are the shortest varieties with a straw length of 79 and 82 cm respectively. There was no lodging in any of the varieties and only a little straw breakage in Oliehavre and Scotty. See results from cultivation plots in table 8.

Table 8. Organically grown oat varieties – cultivation plots, 2024

Oat		Spring	May 31	Before harvest		
		Plant population[1)]	Weeds, % coverage	Straw length, cm	Lodging[1)]	Straw breaking
Varieties						
Ø1	**Scotty**	10	32	95	0	1,5
Ø2	**Fatima**	10	28	101	0	0
Ø3	**Sonja**	10	32	79	0	0
Ø4	**Active**	10	36	90	0	0
Ø5	**Merlin**	10	26	84	0	0
Ø6	**Elison**	10	34	92	0	0
Ø7	**Nemesis**	10	30	88	0	0
Ø8	**NOS Conrad**	10	30	82	0	0
Ø9	**Oliehavre**	10	33	102	0	2,0
Ø10	**Talkito (naked)**	7	88	79	0	0

[1)] Score 0-10, 0=none, 10=dense plant population, complete lodging/broken down.

The kernels of naked oats are smaller than kernels with a hull, and this should be taken into account when examining the quality parameters. Several of the varieties have a high bulk density, ranging from 50.5 to 60.6 kg per hl, with the highest bulk density in Talkito, which is a naked oat. This is followed by Elison with 54.2 kg per hl. Merlin and NOS Conrad have the highest thousand-grain weights of 47.1 and 44.4 g respectively, and Talkito has the lowest thousand-grain weight of 31.6 g followed by Fatima and Active with 34.4 g. This is due to the fact that Talkito and Fatima only have 13 and 28 percent kernels over 2.5 mm and 4 and 3 percent kernels over 2.8 mm, respectively. The fraction below 2 mm is sorted out at the mill. Fatima has 3.8 percent kernels under 2 mm. Merlin and Scotty 88 percent kernels over 2.5 mm and 40 and 36 percent kernels over 2.8 mm, respectively, and only 0.4 and 0.6

percent kernels under 2 mm, respectively. The highest protein content is found in Talkito at 14.8 percent, which is related to the fact that it is a naked oat. Active has a protein content of 13.5 percent, which is high compared to the other varieties, which are between 10.1 and 11.8 percent. The proportion of hulls in the raw material after laboratory dehulling ranges from 20.2 percent in NOS Conrad to 29.8 percent in Oliehavre. The proportion of dehulled kernels is between 90.0 percent in Fatima and 96.9 percent in Oliehavre. See quality parameters for the individual varieties in Table 9.

Table 9. Organically grown oat varieties - quality parameters

Oat		Raw protein, % of DM	Specific weight, kg per hl	TGW, g	Grading, % kernels			Dehulling	
					< 2 mm	> 2,5 mm	> 2,8 mm	Hull in raw material, %	Dehulled kernels, %
Varieties									
Ø1	**Scotty**	10,5	52,4	43,0	0,6	88	36	26,4	96,4
Ø2	**Fatima**	11,8	52,2	34,4	3,8	28	2,6	28,0	90,0
Ø3	**Sonja**	10,8	50,5	42,8	0,7	84	29	27,0	95,8
Ø4	**Active**	13,5	53,7	34,4	1,5	37	4	27,6	91,1
Ø5	**Merlin**	10,3	53,2	47,1	0,4	88	40	24,8	95,7
Ø6	**Elison**	11,0	54,2	43,0	0,9	84	33	21,0	93,7
Ø7	**Nemesis**	11,2	50,8	43,2	0,8	85	27	24,4	94,6
Ø8	**NOS Conrad**	10,1	52,7	44,4	1,1	82	36	20,2	95,1
Ø9	**Oliehavre**	11,4	51,9	39,2	1,7	68	24	29,8	96,9
Ø10	**Talkito**	14,8	60,6	31,6	-	13	4,5	-	-

Conventional cultivation plots

Estimated yields range from 36 to 76 hkg per ha in the different varieties. The lowest yield was obtained in the naked oat Talkito. In common oats, the hulls constitute a significant part of the yield. Although attempts have been made to compensate for low germination in some of the varieties by increasing the seed rate, the plant population has still been relatively low in some of the varieties.

Fatima, Active, Elison and Oliehavre are the tallest varieties with a straw length of 104 to 110 cm. Sonja, Scotty, Talkito and NOS Conrad are the shortest varieties with straw lengths of 94 to 98 cm. There has been little lodging in five of the varieties, but somewhat more in Oliehavre. This may be due to the fact that Oliehavre is a tall variety bred for organic growing conditions, where the height provides competition for weeds, and at the same time the nitrogen input is typically significantly lower than in conventional growing, and thus the growth is not as vigorous as seen under conventional growing conditions. The breaking of straw has been significant in Scotty and NOS Conrad with scores of 7 and 6. See Table 10.

Table 10. Conventionally grown oat varieties – cultivation plots, 2024

Oat		Spring	Before harvest		
		Plant population[1)]	Straw length, cm	Lodging[1)]	Straw breaking
Varieties					
K1	**Scotty**	8	96	0,6	7
K2	**Fatima**	7	104	1,0	1,8
K3	**Sonja**	7	94	0	1,4
K4	**Active**	6	110	0,4	2,2
K5	**Merlin**	6	100	0,6	3,0
K6	**Elison**	7	108	0	1,8
K7	**Nemesis**	8	102	0,4	1,2
K8	**NOS Conrad**	8	98	1,0	6
K9	**Oliehavre**	7	108	4,0	2,3
K10	**Talkito**	7	97	1,3	1,2

[1)] Score 0-10, 0=none, 10=dense plant population, complete lodging/broken down.

Several of the varieties have a relatively high bulk density ranging from 50.8 to 57.6 kg per hl, with the highest bulk density in Talkito, which is a naked oat. Fatima, Active and Elison have bulk densities of over 54 kg per hl. Merlin has the highest thousand-grain weight of 41.5 g, and Talkito has the lowest thousand-grain weight of 27.7 g. The thousand-grain weight is related to the grading, and Talkito, Fatima and Active have a low grading, while Scotty, Sonja and Merlin have a high grading. Fatima has 6.9 percent grains under 2 mm, which is the fraction that is sorted out at the mill. In comparison, Nemesis and Merlin only have 0.7 and 0.9 percent grains under 2 mm, respectively. The highest protein content is found in Active at 13.1 percent, which is high compared to the other varieties ranging between 10.7 and 12.6 percent. See table 11.

Table 11. Conventionally grown oat varieties - quality parameters

Oat		Raw protein, % of DM	Specific weight, kg per hl	TGW, g	Grading, % kernels			Dehulling	
					< 2 mm	> 2,5 mm	> 2,8 mm	Hull in raw material, %	Dehulled kernels, %
Varieties									
K1	**Scotty**	11,2	51,6	38,5	1,8	78	22	29,2	97,9
K2	**Fatima**	12,6	54,3	33,7	6,9	22	2	26,6	94,0
K3	**Sonja**	11,2	51,6	40,5	1,4	77	12	30,8	97,2
K4	**Active**	13,1	54,8	34,0	3,4	22	2	27,6	96,7
K5	**Merlin**	12,0	52,5	41,5	0,9	81	30	26,4	99,0
K6	**Elison**	10,7	54,6	39,9	1,5	65	14	25,2	96,9
K7	**Nemesis**	11,2	52,5	40,0	0,7	72	16	30,8	99,5
K8	**NOS Conrad**	12,0	50,8	38,6	2,2	75	21	27,2	97,9
K9	**Oliehavre**	11,9	51,5	37,6	4,0	56	17	25,8	99,1
K10	**Talkito**	12,1	57,6	27,7	-	5	2	-	

Sensory analyses of harvested grain

Results from the sensory analyses are presented in Table 12, where the samples from the organic and conventional plots are arranged in pairs one after the other. The numeration of the samples is the same as in Tables 8-11. A taste assessment from the sensory specialist has been added, symbolized by a happy or unhappy emoji.

The photo shows the organic and conventionally grown samples laid out in pairs and on the right are samples of the seed. Photo: Lisbeth Ankersen, InnovaConsult

Table 12. Sensory evaluation of harvested and dehulled kernels (laboratory dehulled) – next page

Sample nr.	Scent	Taste		Texture, mouthfeel	Visual
Ø1 Scotty	Mild, grain	Sweet, fat, oats, cream, mild, grain, nut, flour, clean	☺	As from Seed, without the scratchy throat	As from the Seed*
K1 Scotty	Mild, some oat	Oats, cream, grain, flour, bread, nut, slightly bitter aftertaste	☹	As Seed, only a slight scratchy throat	As from the Seed*
Ø2 Fatima	Very mild	Oats, grain, flour, nut, bread, slightly bitter aftertaste	☹	As from the Seed, without the scratchy throat	As from the Seed*
K2 Fatima	Very mild	Flour, oats, a little hay, fat, slightly bitter aftertaste	☹	As from the Seed, without the scratchy throat	As from the Seed*
Ø3 Sonja	Mild, some grain	Flour, grain, oats, a little sweet, nut, fat, cream, slightly bitter af-tertaste	☹	A little hully, otherwise as from the Seed	As from the Seed*
K3 Sonja	Mild, grain	Flour, grain, oats, sweet, fat, nut, bread, cream	☺	As from the Seed*	As from the Seed*
Ø4 Active	Mild, flour, hayloft	Oats, grain, flour, sweet, nut, bread, fat	☺	A little hully, otherwise as from the Seed	As from the Seed*
K4 Active	Mild, some flour	Flour, oats, grain, fat, cream, slightly bitter	☹	As from the Seed*	As from the Seed*
Ø5 Merlin	Mild, flour, hayloft	Sweet, nut, oats, fat, cream, grain, oatmeal, clean	☺	As from the Seed*	As from the Seed*
K5 Merlin	Mild, flour, hayloft, oat	Oats, clean, sweet, fat, cream, grain, bread	☺	As from the Seed*	As from the Seed*
Ø6 Elison	Mild, hayloft	Fat, nut, oats, sweet, grain, flour, bread, oatmeal, cream, grain dust	☺	As from the Seed*	A little less dehulled, other-wise as from the Seed*
K6 Elison	Mild, some flour, hayloft	Oats, sweet, grain, bread, nut, fat, cream	☺	As from the Seed*	As from the Seed*
Ø7 Neme-sis	Mild, some hayloft	Oats, nut, grain, bread, fat, cream, slightly bitter	☺	As from the Seed, without the scratchy throat	Slightly fewer dehulled and without gray areas, otherwise as from Seed*
K7 Neme-sis	Mild, slight basementnote graindust	Fat, cream, oats, nut, bread, grain, hayloft	☹	As from the Seed, without the scratchy throat	Slightly fewer dehulled and without gray areas, otherwise as from Seed*
Ø8 NOS Conrad	Mild	Oats, sweet, fat, cream, grain	☺	As from the Seed, without the scratchy throat	Without gray areas, otherwise as from Seed*
K8 NOS Conrad	Mild, grain-dust	Oatmeal, grain, slightly sweet, flour, bread, nut, fat, clean	☺	As from the Seed, without the scratchy throat	Slightly fewer dehulled and without gray areas, otherwise as from Seed*
Ø9 Olie-havre	Mild, slight grain	Oatmeal, grain, grain dust, bread, fat, nut	☺	As from the Seed, without the scratchy throat	Without gray areas, otherwise as from Seed*
K9 Olie-havre	Mild, grain dust	Oatmeal, grain, flour, bread, nut, sweet, fat, cream, hayloft	☺	As from the Seed, without the scratchy throat	Without gray areas, otherwise as from Seed*
Ø10 Talkito	Mild, slight grain	Sweet, fat, oats, cream, mild, grain, nut, flour, clean	☺	As from the Seed, without the scratchy throat	As from the Seed*
K10 Talkito	Mild, grain	Oatmeal, cereal, bread, nutty, sweet, fatty, slightly bitter	☹	As from the Seed, without the scratchy throat	As from the Seed*

**no notable trends in terms of color, shape or surface seen with the naked eye – however, in a stereo loupe it can be seen that the Seed samples are harder, as they have been peeled manually, i.e. more gently than the cultivated samples.*

Eight samples from the organically grown plots have received a happy emoji, and two a dissatisfied emoji. Six samples from the conventionally grown plots have received a happy emoji, and four a dissatisfied emoji. Merlin, Elison, NOS Conrad and Oliehavre receive a satisfied rating in both organic and conventional. Here again, it should be noted that factors other than the organic/conventional cultivation form can affect the quality and thus the taste experience.

In the cultivated samples, no grains with grayish ends or areas are seen, as was the case in the seed. There are also significantly fewer cases of earthy notes in the aroma and taste of the cultivated samples – notes such as rancid, oxidized and earthy are not found in the cultivated samples. Small differences have been observed between the organic and conventionally grown samples, with bitter taste notes being mentioned more often in conventional samples.

Protein content in the harvested grain

Analyses were made on the dehulled and heat-treated kernels, in contrast to the seed, which was analysed with the hull, with reference to the method section. Table 13 shows that the protein content varies between 11.1 percent in NOS Conrad and 15.3 percent in Active in the organic plots and between 10.9 percent in Scotty and 15.3 percent in Active in the conventional plots. The corresponding values of the dry weight are between 12.1 and 17.0 percent in the organic plots and 12.3 and 17.1 percent in the conventional plots, respectively. Figure 6 shows a graphic representation showing the differences in protein content between the varieties. The figure also shows how the protein content varies between the seed and the harvested kernels from conventional and organic cultivation, respectively.

Table 14 shows corresponding values measured with the NIR method.

Table 13. Protein content in harvested grain

	% protein (g/100 g oat)		% protein (g/100 g dry matter)	
	Ø	**K**	**Ø**	**K**
Scotty	11,4 ± 0,1	10,9 ± 0,0	12,3 ± 0,2	12,3 ± 0,0
Fatima	12,7 ± 0,0	13,6 ± 0,1	14,5 ± 0,0	15,2 ± 0,1
Sonja	12,3 ± 0,0	12,1 ± 0,1	13,5 ± 0,0	13,2 ± 0,1
Active	15,3 ± 0,0	15,3 ± 0,0	17,0 ± 0,0	17,1 ± 0,0
Merlin	11,8 ± 0,2	12,0 ± 0,1	12,9 ± 0,2	13,0 ± 0,1
Elison	11,3 ± 0,8	11,2 ± 0,3	12,6 ± 0,9	12,4 ± 0,4
Nemesis	11,7 ± 0,4	11,8 ± 0,1	13,3 ± 0,5	13,2 ± 0,1
NOS Conrad	11,1 ± 0,3	12,2 ± 0,1	12,1 ± 0,3	13,4 ± 0,1
OlieHavre	12,9 ± 0,0	13,1 ± 0,2	14,2 ± 0,0	14,5 ± 0,2
Talkito	14,0 ± 0,2	13,2 ± 0,7	15,4 ± 0,3	14,6 ± 0,8

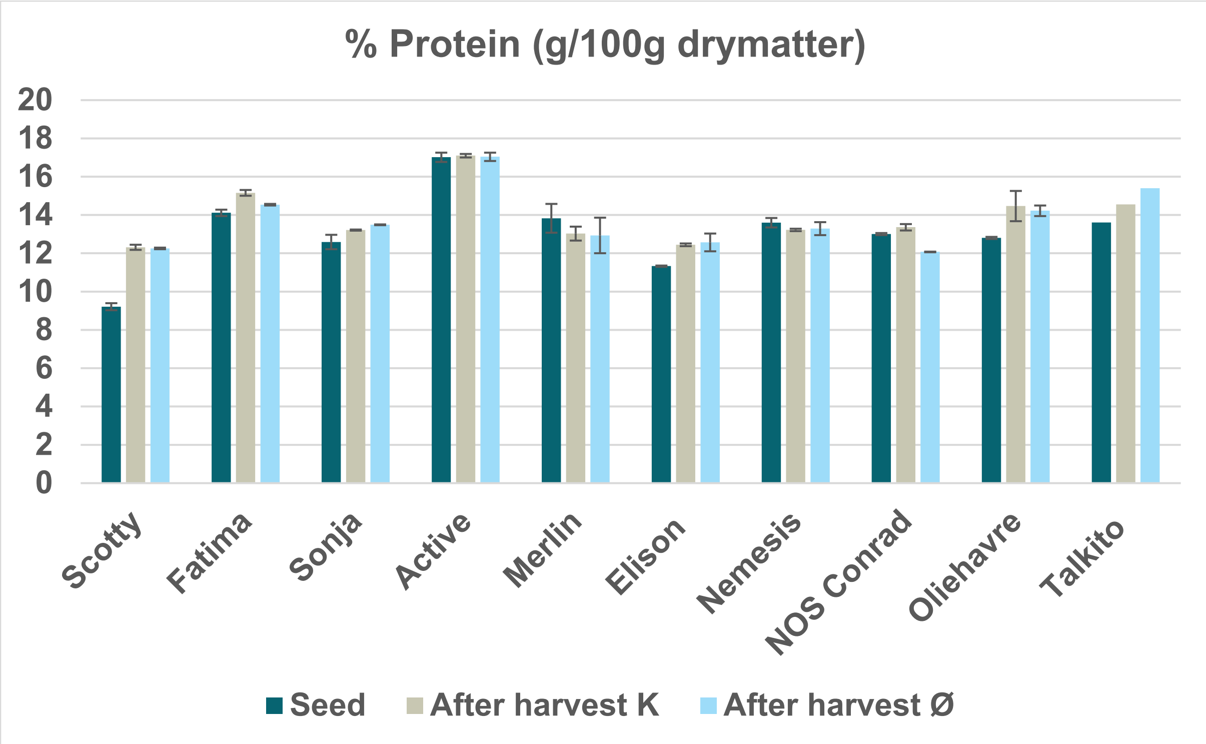


Figure 6. Protein content in dry matter in seed and harvested grain

Table 14. Protein content in the harvested grain, NIR-method

	NIR % DM		NIR % protein		NIR Protein %DM	
	Ø	K	Ø	K	Ø	K
Scotty	91,5	91,2	10,9	11,6	11,9	12,7
Fatima	88,6	90,7	12,0	13,5	13,5	14,9
Sonja	90,6	89,7	12,4	11,7	13,7	13,1
Active	89,2	90,5	15,1	15,8	16,9	17,4
Merlin	90,3	91,9	11,9	12,5	13,1	13,6
Elison	89,1	91,7	11,3	11,7	12,7	12,7
Nemesis	88,7	89,6	12,0	12,0	13,5	13,4
NOS Conrad	91,5	90,2	11,0	12,3	12,0	13,6
OlieHavre	90,6	90,9	12,4	13,2	13,7	14,5
Talkito	90,2	90,6	14,5	13,2	16,0	14,6

Protein analyses (proteomics) – distribution of important proteins in harvested grain

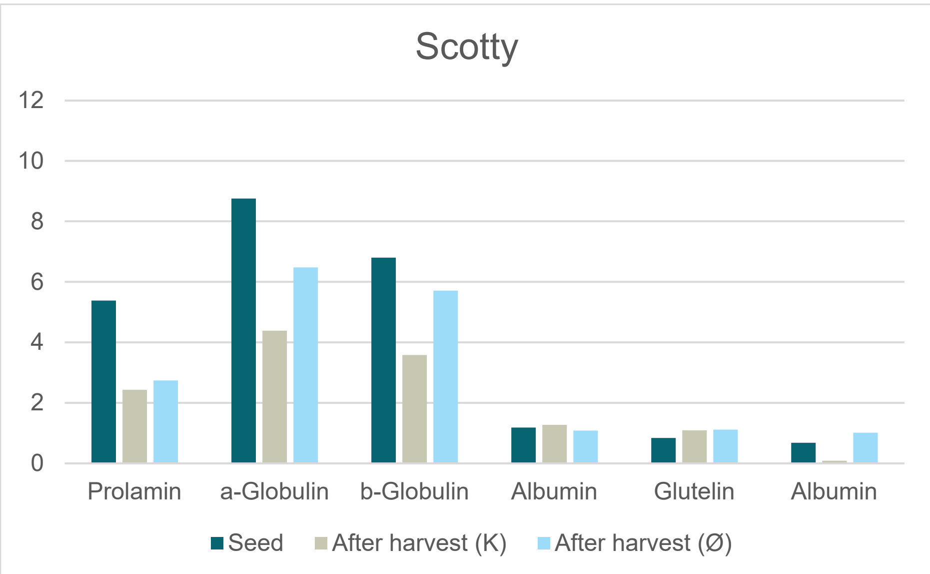
Table 15 shows the percentage distribution of the four main types of protein – namely prolamin, globulin, albumin and glutelin in the harvested and dehulled kernels. In the organic plots, prolamin constitutes between 13 percent in Talkito and 18 percent in NOS Conrad. α-Globulin constitutes between 36 percent in Merlin and Scotty and 40 percent in Active, Oliehavre and Talkito, and β-Globulin constitutes between 29 percent in Nemesis and 34 percent in Talkito. Glutelin constitutes between 5 and 6 percent with several varieties at the same level. Albumin constitutes between 7 percent in Sonja and

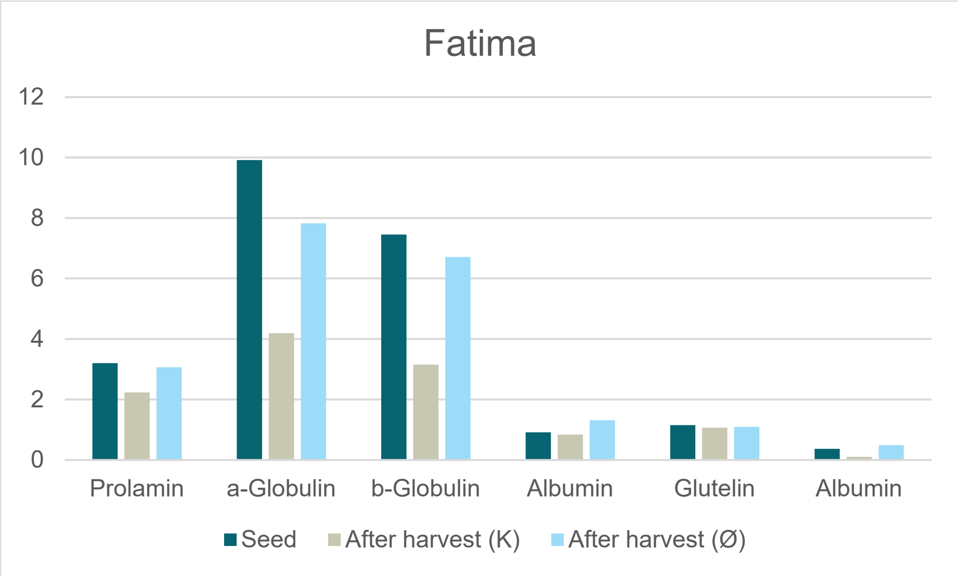
12 percent in Scotty. In the conventional plots, prolamin varies between 15 percent in Merlin and 21 percent in Oliehavre. α-Globulin constitutes between 31 percent in Oliehavre and 37 percent in Sonja and Talkito, and β-Globulin constitutes between 27 percent in Fatima and 35 percent in Talkito. Gluten constitutes between 5 percent in Talkito and 10 percent in NOS Conrad. Albumin constitutes between 8 percent in several varieties and 13 percent in Elison.

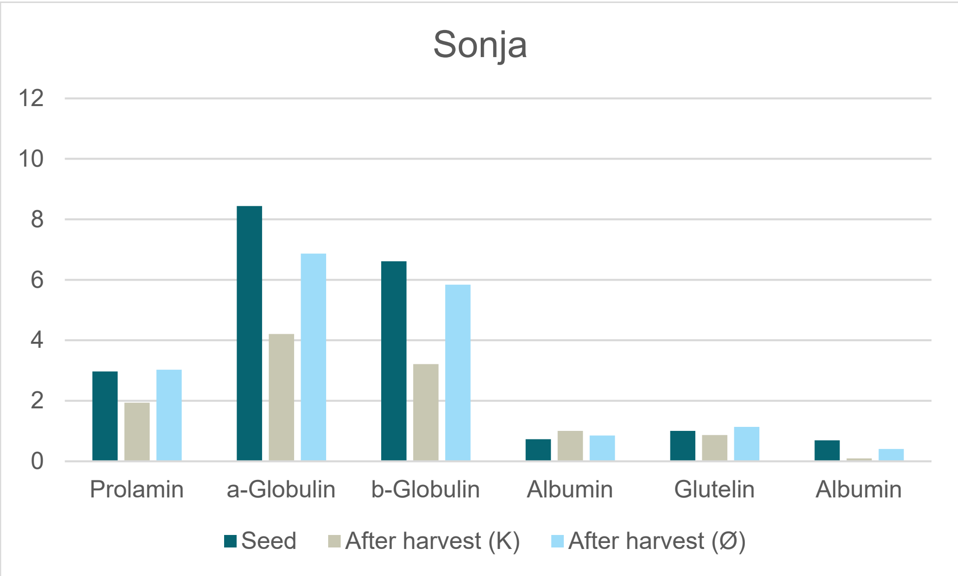
Table 15. Protein distribution in the harvested grain

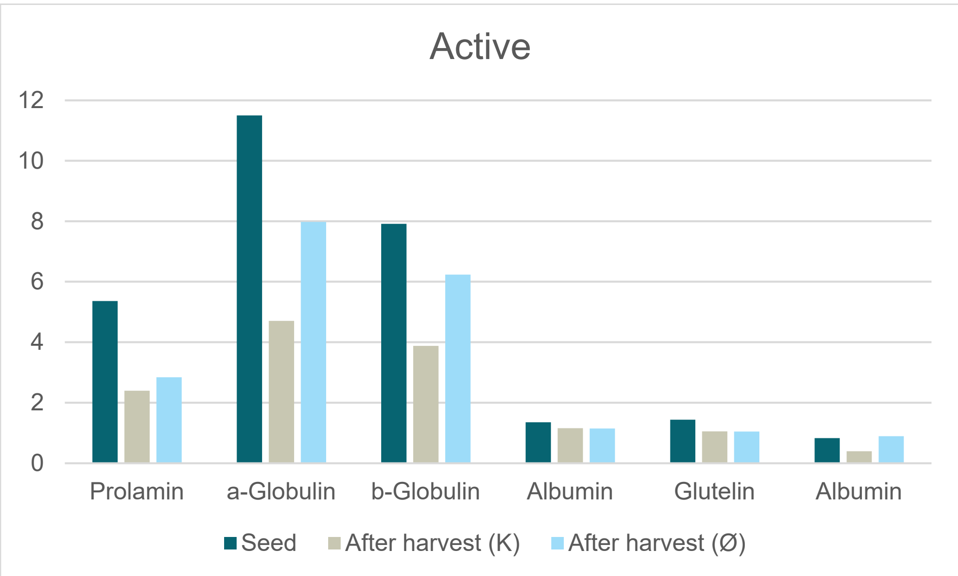
% distribution	Prolamin		α-Globulin		β-Globulin		Glutelin		Albumin	
	Ø	K	Ø	K	Ø	K	Ø	K	Ø	K
Scotty	15	19	36	34	31	28	6	9	12	11
Fatima	15	19	38	36	33	27	5	9	9	8
Sonja	17	17	38	37	32	28	6	8	7	10
Active	14	18	40	35	31	29	5	8	10	11
Merlin	15	15	36	32	33	32	6	8	11	12
Elison	15	16	37	33	32	29	6	9	10	13
Nemesis	17	17	38	35	29	30	5	6	10	12
NOS Conrad	18	20	37	32	30	29	5	10	9	9
OlieHavre	15	21	40	31	33	31	5	9	8	8
Talkito	13	16	40	37	34	35	5	5	8	8

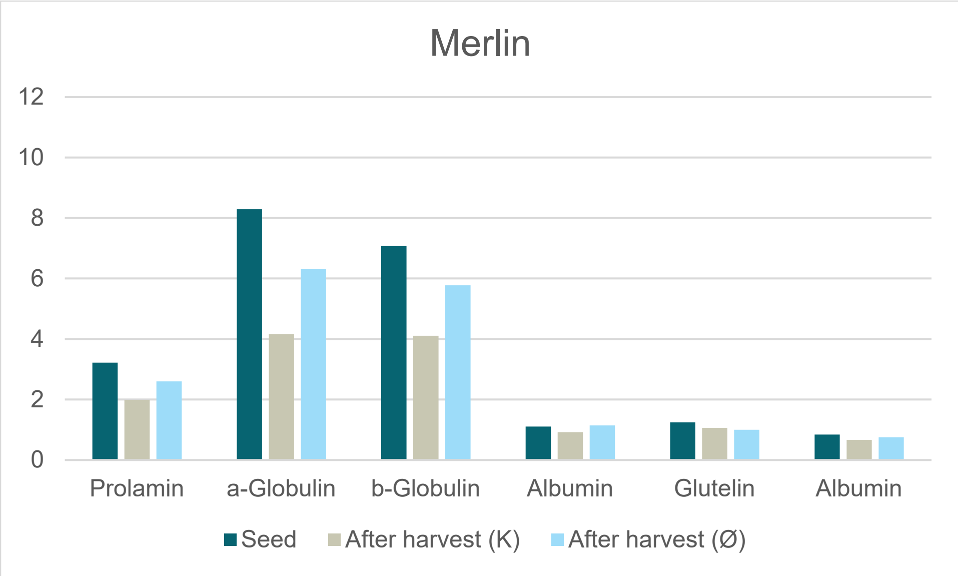
Figure 7 shows the distribution of the individual varieties when comparing the seed (same seed used in organic and conventional plots) and the harvested product from organic and conventional cultivation conditions, respectively. Here too, it should be noted that for the seed, kernels with hulls were analyzed and for the harvested kernels without hulls.




Fatima
12
10
8
6
4
2
0
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)


Sonja
12
10
8
6
4
2
0
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)


Active
12
10
8
6
4
2
0
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)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10
8
6
4
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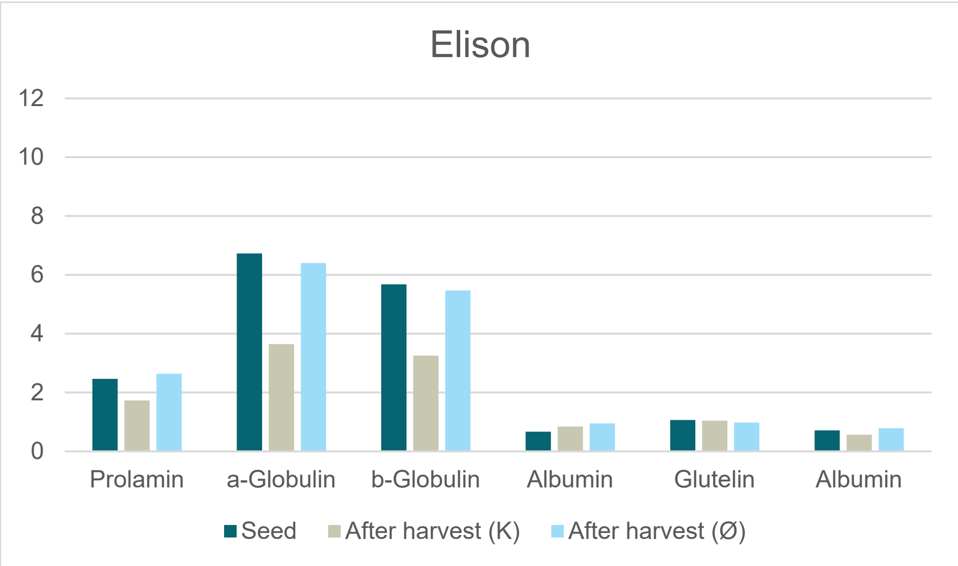
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)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8
6
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2
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Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
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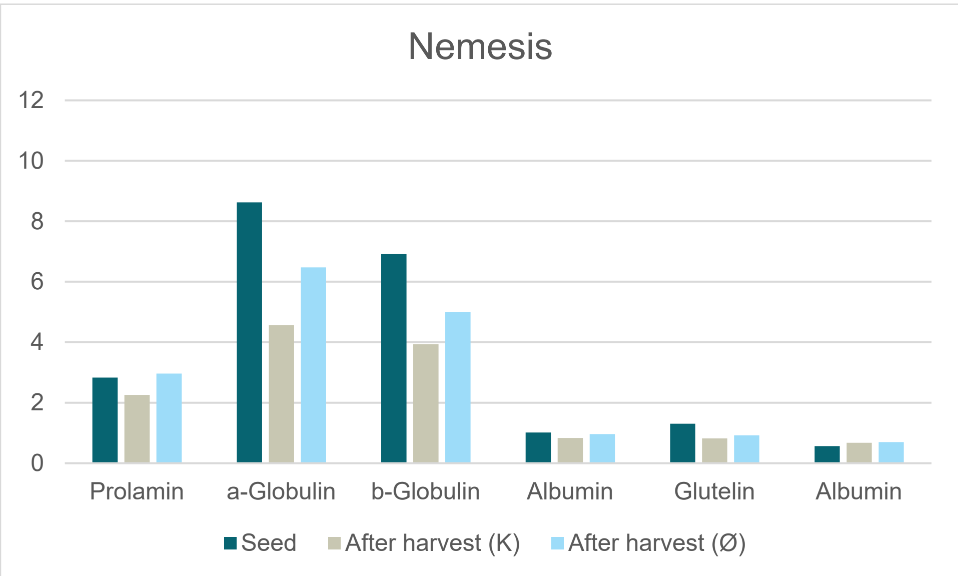
After harvest (K)
After harvest (Ø)


Nemesis
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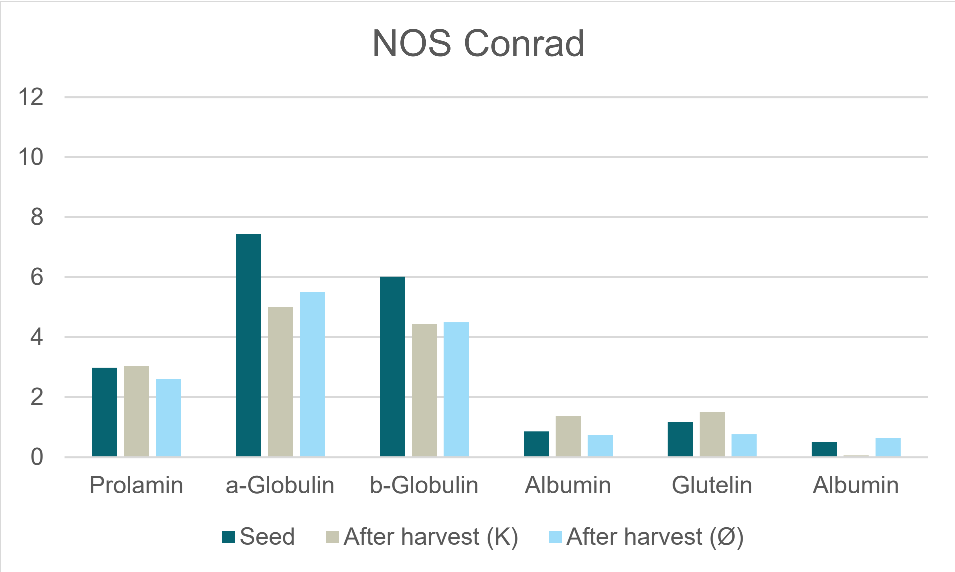
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)


NOS Conrad
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10
8
6
4
2
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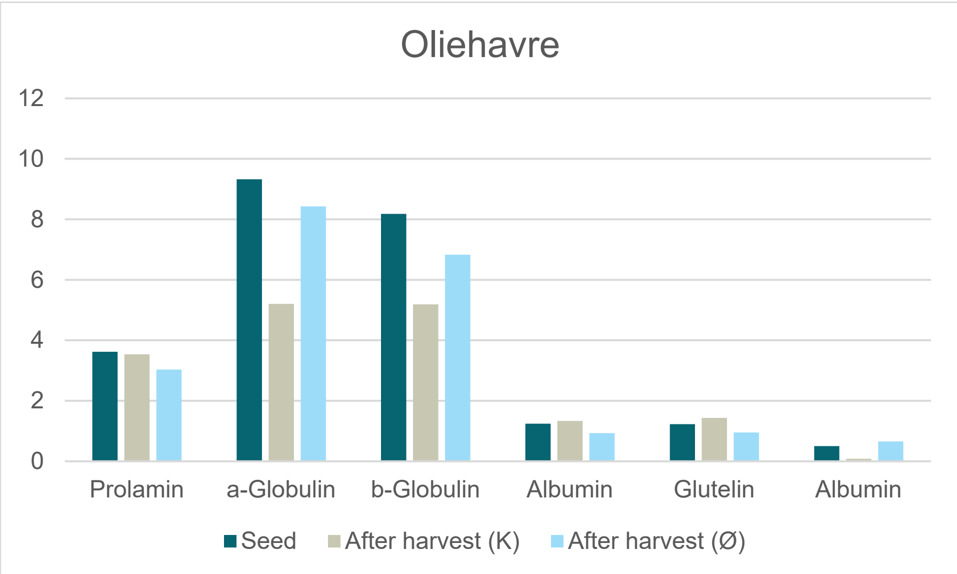
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)


Oliehavre
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10
8
6
4
2
0
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)

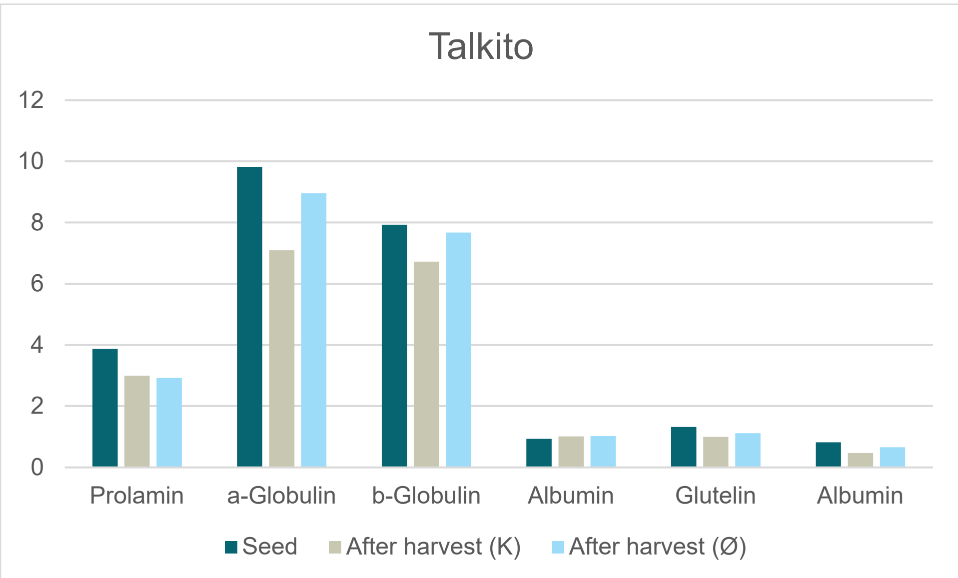

Talkito
12
10
8
6
4
2
0
Prolamin
a-Globulin
b-Globulin
Albumin
Glutelin
Albumin
Seed
After harvest (K)
After harvest (Ø)

Figure 7. Protein distribution in the individual varieties of seed, conventionally and organically grown grains

Protein solubility at different pH-values and salt concentrations in harvested grain

Table 16. Values show average percentage soluble protein at pH 4.5, pH 7.5 and pH 8.5, at three salt concentrations. Conventional harvest samples

	pH 4,5			pH 7,5			pH 8,5		
	0 % NaCl	0.1 % NaCl	0.5 % NaCl	0 % NaCl	0.1 % NaCl	0.5 % NaCl	0 % NaCl	0.1 % NaCl	0.5 % NaCl
Scotty	4,6	4,5	4,7	4,7	5,3	6,2	8,2	8,1	9,4
Fatima	3,9	3,7	3,8	4,0	4,3	5,3	7,9	8,3	9,1
Sonja	5,2	5,6	5,9	6,0	6,3	7,3	9,4	9,8	10,6
Active	4,2	4,4	4,8	4,6	4,9	5,8	7,3	7,6	9,1
Merlin	5,1	5,6	5,6	5,6	6,2	6,9	9,0	8,6	9,8
Elison	4,9	4,9	5,4	4,9	5,5	6,2	7,7	8,0	9,1
Nemesis	3,5	3,4	3,7	3,8	4,0	4,8	6,7	7,2	7,5
NOS Conrad	3,5	3,9	4,1	4,1	4,0	4,9	6,7	7,3	8,4
OlieHavre	3,3	3,0	3,4	3,8	3,7	4,2	6,0	6,4	7,2
Talkito	3,0	3,3	3,6	3,7	4,0	4,8	6,3	6,7	7,6

Table 17. Values show average percentage soluble protein at pH 4.5, pH 7.5 and pH 8.5, at three salt concentrations. Organic harvest samples

	pH 4,5			pH 7,5			pH 8,5		
	0 % NaCl	0.1 % NaCl	0.5 % NaCl	0 % NaCl	0.1 % NaCl	0.5 % NaCl	0 % NaCl	0.1 % NaCl	0.5 % NaCl
Scotty	4,7	4,9	5,8	5,5	6,6	7,1	11,0	10,8	11,9
Fatima	3,4	3,5	3,4	3,9	3,9	5,0	7,7	8,2	9,4
Sonja	7,0	6,7	7,9	7,7	8,0	9,3	12,1	12,2	13,0
Active	4,8	5,4	5,4	5,2	5,2	6,2	8,5	8,5	9,5
Merlin	5,2	5,5	5,7	5,2	5,6	6,6	8,3	8,0	8,4
Elison	6,2	5,9	6,4	6,1	6,6	7,3	8,6	8,8	8,9
Nemesis	3,9	4,4	4,7	4,8	5,4	6,5	8,0	8,5	9,0
NOS Conrad	4,7	5,3	5,7	5,4	5,2	7,0	8,5	8,5	8,1
OlieHavre	4,3	4,3	4,5	4,5	4,7	5,4	7,1	7,5	8,3
Talkito	4,5	4,6	4,7	4,5	4,9	5,8	7,5	8,2	8,5

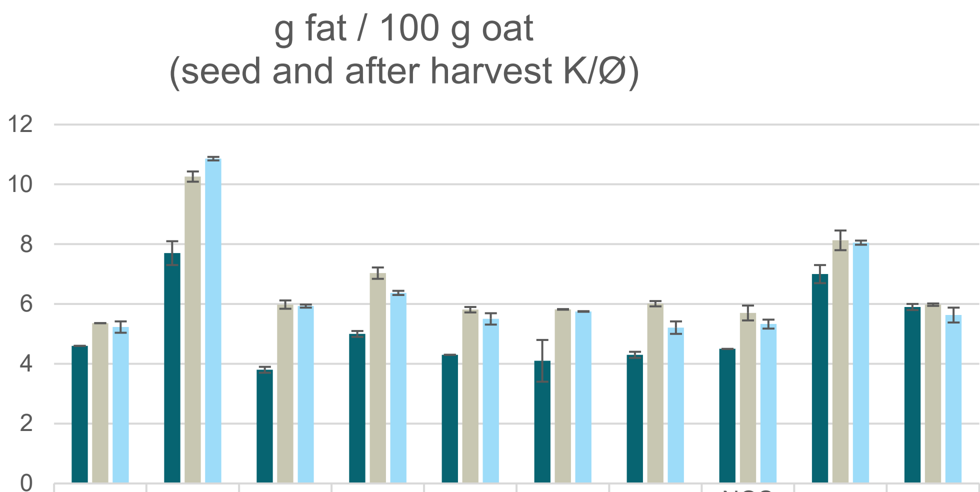
Protein solubility is generally lower in the harvested product compared to the seed. Solubility is generally highest at higher pH and salt concentrations across varieties and cultivation methods. Sonja is the variety with the highest protein solubility.

Fat content and unpolar fat in the harvested grain

The analyses were made on the harvested and dehulled kernels. The fat percentage was highest in Fatima in both organic and conventional harvest samples and lowest in Scotty and other varieties. The proportion of non-polar fat was generally higher than in the seed, and highest in Fatima. The proportion of non-polar fat out of the total weight of the kernel is also highest in Fatima. See Table 18 and Figure 8-10.

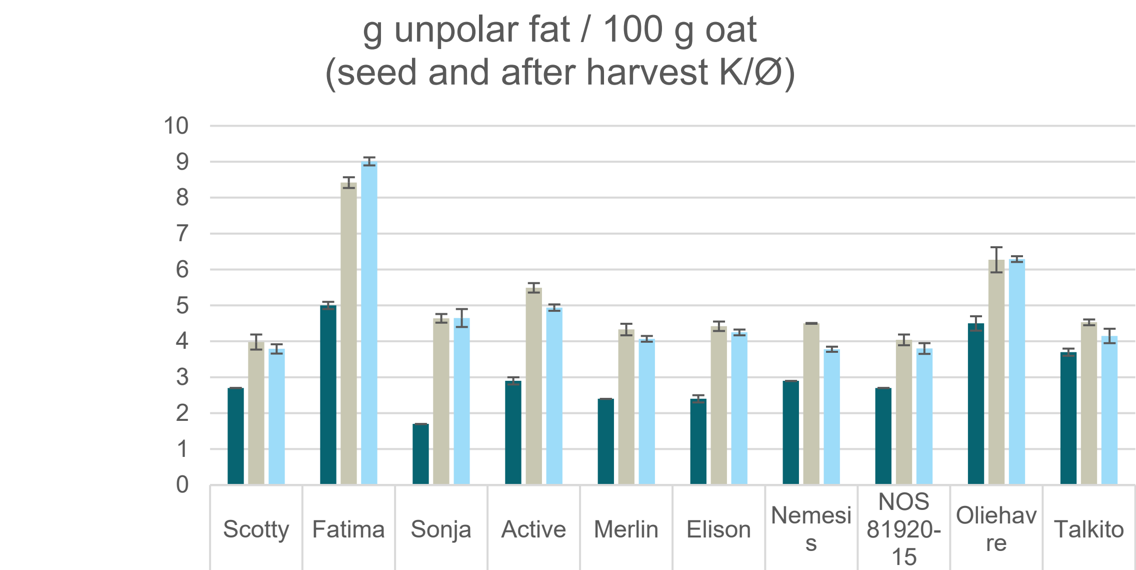
Table 18. Fat content and proportion of non-polar fat in oat kernels

	% fat in kernel (g/100g)		% upolar fat (g/100 g fedt)		g unpolar fat/100 g kernel	
	Ø	K	Ø	K	Ø	K
Scotty	5,2 ± 0,2	5,4 ± 0,0	72,4 ± 0,2	74,2 ± 3,8	3,8 ± 0,1	4,0 ± 0,2
Fatima	10,9 ± 0,1	10,3 ± 0,2	82,9 ± 0,5	82,2 ± 2,8	9,0 ± 0,1	8,4 ± 0,2
Sonja	5,9 ± 0,1	6,0 ± 0,1	78,4 ± 4,8	77,6 ± 0,1	4,7 ± 0,3	4,6 ± 0,1
Active	6,3 ± 0,1	7,0 ± 0,2	77,5 ± 2,2	78,1 ± 0,2	4,9 ± 0,1	5,5 ± 0,1
Merlin	5,5 ± 0,2	5,8 ± 0,1	73,9 ± 1,2	74,5 ± 1,7	4,1 ± 0,1	4,3 ± 0,2
Elison	5,8 ± 0,0	5,8 ± 0,0	74,1 ± 1,4	75,9 ± 2,2	4,3 ± 0,1	4,4 ± 0,1
Nemesis	5,2 ± 0,2	6,0 ± 0,1	72,6 ± 1,6	75,0 ± 0,9	3,8 ± 0,1	4,5 ± 0,0
NOS Conrad	5,3 ± 0,2	5,6 ± 0,3	71,3 ± 0,8	72,6 ± 0,6	3,8 ± 0,2	4,0 ± 0,2
OlieHavre	8,1 ± 0,1	8,1 ± 0,3	78,2 ± 0,3	77,1 ± 1,1	6,3 ± 0,1	6,3 ± 0,4
Talkito	5,6 ± 0,3	6,0 ± 0,0	73,7 ± 0,3	75,7 ± 1,9	4,2 ± 0,2	4,5 ± 0,1



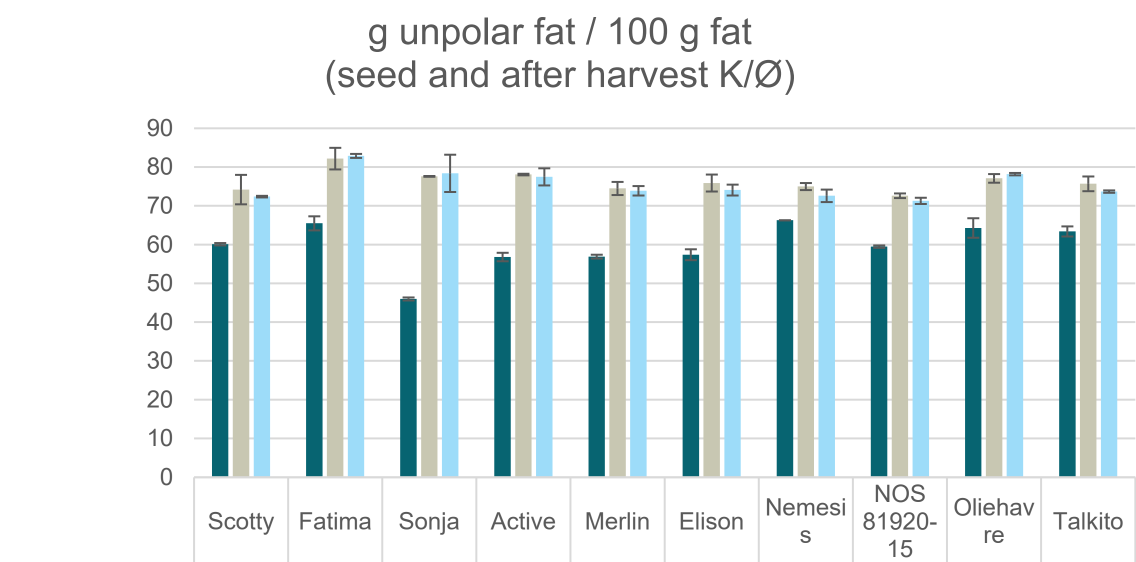
	Scotty	Fatima	Sonja	Active	Merlin	Elison	Nemesis	NOS 81920-15	Oliehavre	Talkito
Seed	4,6	7,7	3,8	5	4,3	4,1	4,3	4,5	7	5,9
After harvest (K)	5,36	10,26	5,98	7,03	5,81	5,82	6,01	5,7	8,13	5,98
After harvest (Ø)	5,23	10,86	5,93	6,37	5,5	5,75	5,21	5,33	8,05	5,63

Figure 8. Fat content in seeds and harvested grains from conventional and organic cultivation.



	Scotty	Fatima	Sonja	Active	Merlin	Elison	Nemesis	NOS 81920-15	Oliehavre	Talkito
Seed	2,7	5	1,7	2,9	2,4	2,4	2,9	2,7	4,5	3,7
After harvest (K)	3,98	8,42	4,64	5,49	4,33	4,42	4,5	4,04	6,27	4,53
After harvest (Ø)	3,79	9,01	4,65	4,94	4,07	4,25	3,78	3,8	6,29	4,15

Figure 9. The proportion of non-polar fat in oats from seed and harvested grains from conventional and organic cultivation, respectively.



	Scotty	Fatima	Sonja	Active	Merlin	Elison	Nemesis	NOS 81920-15	Oliehavre	Talkito
Seed	60,1	65,5	46	56,8	56,9	57,4	66,3	59,5	64,3	63,4
After harvest K	74,2	82,2	77,6	78,1	74,5	75,9	75	72,6	77,1	75,7
After harvest Ø	72,4	82,9	78,4	77,5	73,9	74,1	72,6	71,3	78,2	73,7

Figure 10. The proportion of non-polar fat out of the total amount of fat in seeds and harvested grains from conventional and organic cultivation, respectively.

When comparing values for seed and the harvested product, it is again important to note that the analyses of the seed were done with hulled kernels and after harvest on the dehulled product.

Fat content (NIR) and peroxidase activity in harvested grain

Table 19 shows the fat content in the harvested grain and the results of the peroxidase test using Peroxidase Test MQuant from MERCK. "+" "(x)" means that there is low activity of peroxidase enzymes. All samples show activity, which was first believed, could be the reason why off-notes have been registered in all samples later. The peroxidase activity results obtained with this method were not directly comparable to those provided by Valsemøllen. Their analytical method differed in principle, sensitivity (special towards oat matrices), and calibration approach. Due to the lack of methodological suitability, data generated with Peroxidase Test MQuant could not be reliably interpreted against Valsemøllen's reference values. Another testing regime using Peroxtesmo KO peroxidase test paper from Macherey-Nagel confirmed the inicial negativity on residual peroxidase.

The highest fat content is seen in the variety Fatima followed by Oliehavre, consistent with previous results, and the lowest content in Scotty and several of the other varieties.

Table 19. Fat content and peroxidase activity in harvested grain

Variety	NIR % DM		NIR fat %		NIR fat % of DM		Peroxidase-test	
	Ø	K	Ø	K	Ø	K	Ø	K
Scotty	91,5	91,2	6,7	6,2	7,4	6,8	+	(+)
Fatima	88,6	90,7	11,9	10,9	13,4	12,0	+	(+)
Sonja	90,6	89,7	6,9	6,9	7,6	7,7	+	(+)
Active	89,2	90,5	8,1	8,5	9,1	9,3	(+)	(+)
Merlin	90,3	91,9	6,9	7,1	7,7	7,8	+	+
Elison	89,1	91,7	6,8	7,3	7,7	7,9	+	+
Nemesis	88,7	89,6	6,8	7,1	7,6	7,9	+	+
NOS Conrad	91,5	90,2	6,9	6,8	7,5	7,6	+	+
OlieHavre	90,6	90,9	9,8	9,6	10,8	10,5	+	+
Talkito	90,2	90,6	6,9	7,4	7,6	8,2	+	+

Free fatty acid distribution and total amount in harvested grain

Table 20. Concentration of free fatty acids (mg/kg).

	Linolenic acid (18:3)		Linoleic acid (18:2)		Oleic acid (18:1)		Stearic acid (18:0)		Palmitic acid (16:0)		Total amount	
	Ø	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**
Scotty	37	49	257	396	142	129	104	66	258	218	799	859
Fatima	51	68	782	889	433	381	128	75	340	263	1734	1675
Sonja	48	64	452	645	251	230	112	71	285	258	1148	1268
Active	40	55	367	565	177	172	108	70	274	238	966	1100
Merlin	44	38	455	349	185	129	113	74	278	227	1074	817
Elison	40	44	308	403	169	142	116	71	279	233	911	892
Nemesis	52	51	494	464	289	175	110	71	296	248	1242	1009
NOS Conrad	46	39	428	348	225	138	124	68	304	232	1126	826
OlieHavre	53	54	685	674	405	290	114	74	329	275	1586	1367
Talkito	46	43	423	446	224	178	112	85	271	247	1075	999

There is a large difference in the fatty acid distribution between the varieties, see table 20. However, ranges were interpreted to be present in expected said normal levels.

Results, oat base

Sensory analyses of oat base

An initial sensory evaluation of the first batch of oat bases produced has been carried out at Döhler, which has revealed a problem. All UHT-treated samples showed “off-notes” or had an undesirable aftertaste, which was further described as strongly umami-like. The oat base before UHT was not tasted. As Döhler used a well-established standard process for hydrolysis and extraction of oat kernels, these results were very unexpected and resulted in an extensive analysis of the cause. It was jointly decided to carry out a different process on selected varieties to solve this problem.

Sensory assessment from Döhler is shown in Tables 21 and 22.

Table 21. Sensory evaluation of oat bases, first processing

	Sensory evaluation – after UHT	
	Organic (O)	**Conventional (C)**
Scotty	much more bitter, more powdery, off taste	a bit bitter, powdery, off taste
Fatima	powdery, umami off-taste	powdery, off taste
Sonja	powdery, off taste	darker, powdery, off taste
Active	off-taste	off-taste
Merlin	very powdery, off-taste	powdery
Elison	off-taste	off-taste
Nemesis	off-taste	off-taste
NOS Conrad	more sediment, bitter, off taste	dark, more sediment, bitter, off taste
OlieHavre	off-taste	off-taste
Talkito	brighter, smells like rubber, off taste	brighter, rubber like off taste

Table 22. Sensory evaluation of oat bases, second processing

	Sensory evaluation	
	After concentration	**After UHT treatment**
Scotty K	slightly bitter, oat	off taste slightly rancid
Sonja K	mild, less bitter, oat	off taste rancid
Active K	oaty, not bitter	off taste rancid
NOS Conrad K	oaty, not bitter	off taste rancid
OlieHavre K	more bitter, slightly rancid	off taste slightly rancid
Oliehavre Ø	slightly bitter, oat	more neutral, minimal off taste

The sensory profile was improved in the oat bases with the second process, but was still not considered to be of standard quality. In addition, it was noted that the off-taste was more pronounced after the UHT treatment.

In the subsequent sensory analysis of the oat bases at InnovaConsult, a search was made for possible reasons for these "off-notes".

The following pages describe a sensory evaluation carried out by InnovaConsult, as well as a search for possible explanations for deviations in taste in the oat base.

Table 23. Natural flavor and aroma compounds in oats – likely off-notes

Sensory category	Compound / Group	Chemical Class	Possible origin /reaction	Sensory effect
Throat irritation / burning	Hexanal, 2,4-Decadienal, (E,E)-2,4-Nonadienal	Aldehydes (lipid oxidation)	Oxidation of linoleic acid / oleic acid	Sweaty, fatty, tallow, waxy, irritating, harsh
	Ferulic acid derivatives (2-methoxyphenol / guaiacol)	Phenols	Lignin degradation under heat	Dry, rough, burning
	Avenacosides (large polar saponins, not in GC–MS but in matrix)	Saponins	Naturally in oats	Bitter, metallic, throat irritation
Animal / barnyard	Butanoic acid, 3-Methylbutanoic acid, Hexanoic acid	Short-chain fatty acids	Hydrolysis of triglycerides	Barnyard, sour milk, cheesy
	Dimethyl sulfide (DMS), Dimethyldisulfide (DMDS), Methional	Sulfur compounds	Methionine degradation (Maillard)	Cooked cabbage, animalic, barnyard
	Pyridine, Methylpyridine, Benzothiazole	N- and S-heterocycles	Thermal protein degradation	Burnt, barnyard, earthy
	Guaiacol, Vinylguaiacol	Phenols	Thermal lignin degradation	Smoky, barnyard
Bitter / harsh	Avenacoside A/B, Pyrazine, Guaiacol	Saponins, heterocycles, phenols	Maillard / oxidation	Bitter, rancid, roasted
	2,4-Decadienal, 2,4-Nonadienal	Aldehydes	Secondary lipid oxidation	Bitter, fatty, papery
	Furfural, 5-Methylfurfural, 5-HMF	Furans	Maillard products	Bitter, dry, baked
Umami / broth	Methional, 2-Acetyl-1-pyrroline, Pyrazine	Sulfur–Maillard products	Heat treatment of amino acids	Umami, broth, bread crust
	Dimethyl sulfide (DMS)	Sulfur compound	Degradation of methionine	Savory, sweet umami
	β-Damascenone	Norisoprenoid	Carotenoid degradation	Umami/savory/balanced, floral, fruity, complex

Rancid / oxidative	Hexanal, Heptanal, Octanal, Nonanal, Decanal	Aldehydes (oxidation markers)	Lipid oxidation	Papery, rancid, cardboard-like
	2,4-Decadienal / 2,4-Nonadienal	α,β-unsaturated alde-hydes	Secondary oxidation	Rancid, old oil
	2-Heptanone, 2-Octanone	Ketones	Fatty acid oxidation	Oily, blue-cheese-like
Stale / papery / old grain	Benzaldehyde, Vanillin, 2-Furfural (in low sugar / low fat solutions)	Aromatic aldehydes / furans	Lignin and sugar degradation	Burnt, woody, stale
	2,4-Decadienal, 2-Nonenal	Aldehydes	Lipid oxidation	Papery, old-grain
Other off-notes	Acetic acid	Short-chain acid	Fermentative byproduct	Sour, pungent
	Isophorone	Cyclic ketone	Degradation of carotenoids / fatty acids	Medicinal, plastic
	Phenylacetaldehyde	Aromatic aldehyde	Degradation of phenylalanine	Sweet, heavy notes
	1-Octen-3-one / 1-Octen-3-ol	Ketone / alcohol	Lipid oxidation of linoleic acid	Earthy, mushroom-like, metallic

Table 24. Matrix-dependent differences in flavor and aroma perception – typical compounds in oat drink

Compound	Chemical class / origin	In sweet / fat matrix	In grain / oat drink matrix	Comment / explanation
Vanillin	Phenolic aldehyde (from lignin or addition)	Sweet, creamy, balsamic, 'vanilla'	Dry, dusty, woody, papery	Lack of sugar/fat → loss of sweetness perception, emphasizes aldehydic 'sharpness'
Guaiacol	Methoxyphenol (from ferulic acid / lignin)	Smoky, sweet, 'caramelized' (in small doses)	Barnyard, burnt, medicinal	In cereal matrix, phenolic note seems 'impure' due to lack of balancing sweetness
Furfural / 5-Methylfurfural	Furans (from sugars / amino acids via Maillard)	Caramel, baked, honey	Dry, papery, bread crust	Low sugar and high water activity → loss of sweetness, perception shifts toward 'tart'
Methional	Sulfur-containing aldehyde (from methionine)	Broth, bread crust, umami	Cooked cabbage, barnyard, 'old soup'	Oxidation + lack of salt/fat enhances animalic/barnyard-like tone
Hexanal / 2,4-Decadienal	Aldehyde (from lipid oxidation)	Nutty, fresh, green (at low concentration)	Rancid, cardboard, harsh	At higher concentration or during storage → oxidative off-note
Isophorone	Cyclic ketone (from carotenoids / lipids)	Mild floral/plastic (masked by sweetness)	Medicinal, solvent-like	Sweet/fatty components usually mask the 'chemical' odor

Table 25. Chemical processes and sensory off-notes in oat drink – with short explanations

Process	Typical compounds	Sensory note	Short explanation
Lipid oxidation	Hexanal, 2,4-Decadienal, Nonanal	Rancid, dusty, harsh	Fatty acids in oats react with oxygen to form aldehydes – give rancid and papery notes, especially during storage.
Maillard reaction	Pyrazines, Methional, Furfural, 2-Acetylpyrroline	Umami, bitter, burnt	Sugars and amino acids react during heating – give color and flavor but can turn bitter or burnt at high temperatures.
Lignin / phenol degradation	Guaiacol, Vanillin	Barnyard, smoky, woody	Degradation of plant fibers and husk releases phenols, which can produce smoky or woody notes.
Fat hydrolysis	Butanoic acid, Isovaleric acid	Barnyard, sour, cheesy	Enzymes or microbes break down fats into short-chain acids – smell sour, animalic, or cheesy.
Protein degradation	Pyridines, Thiazoles	Barnyard, earthy	Degradation of proteins and amino acids under heat forms nitrogen- and sulfur-containing compounds with strong, earthy odors.
Heat / storage	1-Octen-3-one, Benzothiazole	Earthy, medicinal, rancid	Prolonged heating or storage promotes oxidation and Maillard by-products – causes 'stale' or medicinal flavor.

Lipid Oxidation

Fat + O_2 → Lipid peroxides (hydroperoxides) → Aldehydes / Ketones
(Compounds: Hexanal, 2,4-Decadienal)
→ Rancid, dusty note

Maillard Reaction

Amino acids + Sugar → Pyrazines, Furfural, Methional
→ Umami, burnt, bitter

Phenol Degradation

Ferulic acid → Guaiacol, Vanillin
→ Woody, barnyard, smoky

Protein Degradation

Amino acids → Pyridines, Thiazoles
→ Earthy, barnyard, sulfurous

Fat Hydrolysis

Triglyceride + H_2O → Glycerol + Short-chain acids
(Compounds: Butanoic, Isovaleric)
→ Sour, cheesy, animalic

Note: 'Hydroperoxide' (ROOH) is an organic intermediate product in lipid oxidation and not the same as 'hydrogen peroxide' (H_2O_2).

Figure 11. How functional groups change during processing in oat drink

Table 26. Where in the process off-notes can arise in oat drink

Process Step	Chemical Reactions / Changes	Typical Compounds	Sensory Effect / Off-Note
Harvest	Slight enzymatic activity in fresh grain, initial oxidation of fats if the grain is moist	Hexanal, 2,4-Decadienal	Green, grassy or slightly rancid notes (early oxidation)
Storage	Slow lipid oxidation, microbiological activity, possible heat or moisture influence	Aldehydes (nonanal, hexanal), acids (butanoic, isovaleric acid)	Rancid, papery, barnyard, old grain
Dehulling	Release of phenolic compounds from husk and cell walls	Guaiacol, ferulic acid derivatives	Barnyard-like, bitter, slightly harsh
Milling	Increased surface area → higher enzymatic activity (lipase, lipoxygenase), initial oxidation	2,4-Decadienal, hexanal, 2-nonenal	Fresh-rancid, papery, harsh
Heating / Pasteurization (enzyme inactivation)	Maillard reactions, thermal degradation of amino acids and sugars	Pyrazines, methional, furfural, 2-acetyl-1-pyrroline	Umami, burnt, bitter, 'cooked'

Continued..

Process step	Chemical reactions / changes	Typical compounds	Sensory effect / off-note
Mixing into syrup / extract (enzyme treatment)	Amylases and proteases form flavor-active intermediates; possible oxidation in open process	2,4-Decadienal, aldehydes, acids	Bitter, rancid, sweet-oxidative
Dilution to final drink	Dissolution of saponins, phenols, and fatty acid oxidation products	Avenacosides, guaiacol, hexanal	Metallic, rough, throat irritation
Pasteurization of syrup or final drink	Thermal stress → further Maillard and oxidation reactions	Furfural, isophorone, methional	Bitter, barnyard, burnt
Filling and storage	Oxygen ingress, light degradation of fats and pigments	Aldehydes, ketones, acids, β-damascenone	Rancid, papery, earthy, medicinal

Table 27. Overview, oat base samples

Nr.	Name	Nr. (UHT treated)	Name
A	K1 Scotty	Au	K1 Scotty
B	K3 Sonja	Bu	K3 Sonja
C	K4 Active	Cu	K4 Active
D	K8 NOS Conrad	Du	K8 NOS Conrad
E	K9 Oliehavre	Eu	K9 Oliehavre
F	O9 Oliehavre	Fu	O9 Oliehavre
D1	Döhler dilution 4,5	D2	Döhler dilution 4,5

On the next page you can see a photo of the oat bases, with corresponding numbering on the left side.

Du Eu Fu

Au Bu Cu

D E F

A B C

D1 D2

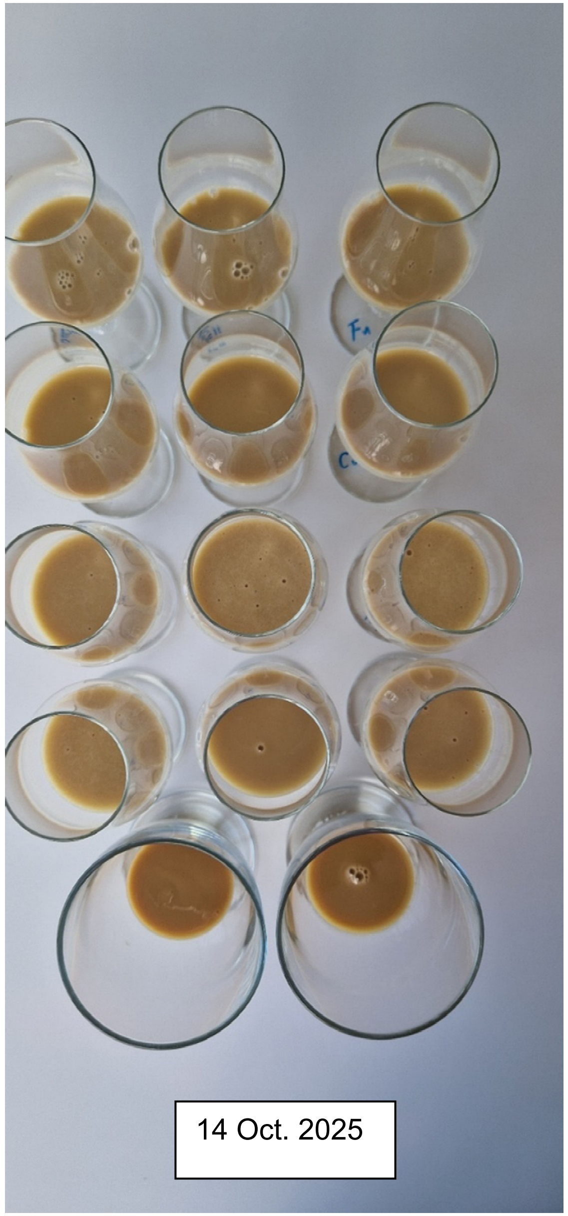


Table 28. Sensory table – all diluted samples (green = positive, red=negative)

Sample	Taste and Aroma, Not Pasteurized (D1, D2 and A–F)	Taste and Aroma, Pasteurized (Au to Fu)
D1 (diluted)	Oat, sweet, milk, slight cocoa milk, cream	
D2 (diluted)	Sweet, milk, oat, mild, slightly less sweet/creamy than D1, slightly tangy-sweet, slight fruit, milk, cream	
A (diluted)	Slightly rancid, slightly earthy, oat hulls, oat, grain loft, flat, slight cream, grain dust	Oat, slight soup/broth/chicken stock, rich, sweet, slight umami, slight rancid
B (diluted)	Oat, slight cream, slight barnyard, flat, watery, light bitter aftertaste	Slight chicken stock, slight quorn, oat, slight cream, rich, sweet, slight umami, light bitter aftertaste
C (diluted)	Oat, health store/cereal, very faint rancid hint, slight cream, slightly tangy-sweet, light rancid aftertaste	Slight soup/meat/chicken stock, slight oat, slightly sweet, rich, slight umami, slight cream, light bitter aftertaste
D (diluted)	Oat, mild, grain loft, sweet, light cream	Oat, mild, slight chicken stock/quorn, rich, slightly sweet, slight cream, slight umami, light bitter aftertaste
E (diluted)	Grain dust, grain loft, oat, sweet, watery, light cream	Oat, mild, slight chicken stock/quorn, rich, slightly sweet, slight cream, slight umami, light bitter aftertaste
F (diluted)	Mild, oat, light cream, sweet, slight bitter aftertaste	Oat, slight chicken stock, rich, slight umami, slight cream, slight bitter aftertaste

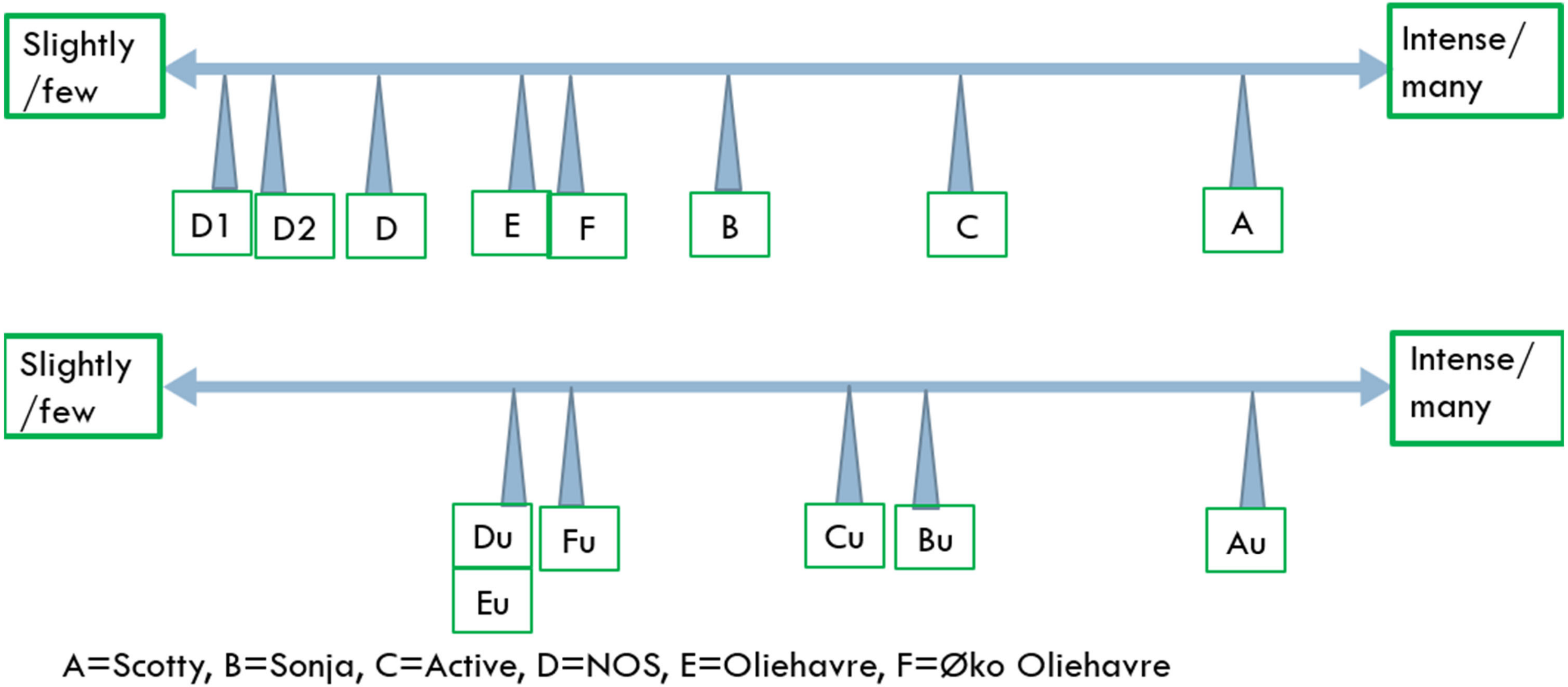


Figure 12. Off-note-barometer, diluted samples

Trends from sensory tests

- D1 and D2 generally have fewer off-notes but are also darker in color than the other samples.
- Scotty is the most problematic, both concentrated and diluted.

Sensory results compared with literature and databases

- Matrix influences flavor and aroma of VOC's.
- Lipid oxidation (to aldehydes), Maillard reaction, lipid hydrolysis, and protein degradation (enzymatic or thermal) are the most likely causes of off-notes.
- Aldehydes are the group responsible for most of the recorded off-notes.
- Aldehydes can form during harvest, storage, milling, heating, syrup mixing, dilution to final drink, pasteurization, and storage.

pH, fat- og protein content in oat base

Table 29 and 30 shows analyses of oat base after UHT treatment. The highest protein content is in Fatima and Active, and the lowest protein content is in Elison, NOS Conrad and Scotty. Fatima has the highest fat content, followed by Oliehavre, and the lowest fat content is in Scotty.

Table 29. pH, fat, protein in oat bases from ten oat varieties (first series).

	pH		NIR % DM		NIR % fat		NIR fat % of DM		NIR % protein		NIR protein % of DM	
	Ø	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**
Scotty	6,5	6,7	47,5	47,1	2,7	2,6	5,8	5,6	4,5	4,7	9,5	9,9
Fatima	6,3	6,3	53,6	50,7	6,9	5,8	12,9	11,4	7,4	7,0	13,8	13,8
Sonja	6,4	6,5	46,3	48,2	3,1	3,2	6,7	6,7	4,7	5,1	10,2	10,5
Active	6,5	6,4	48,3	49,1	3,8	3,9	8,0	8,0	6,7	6,7	13,9	13,6
Merlin	6,5	6,4	47,7	47,2	2,9	2,8	6,1	6,0	4,8	4,9	10,1	10,4
Elison	6,8	6,5	46,7	47,8	3,2	3,2	6,9	6,6	4,3	4,6	9,1	9,6
Nemesis	6,5	6,3	45,8	47,1	3,1	3,1	6,8	6,6	5,0	4,8	10,9	10,1
NOS Conrad	6,5	6,5	46,9	46,3	2,9	2,8	6,2	6,0	4,3	4,4	9,2	9,6
Oliehavre	6,2	6,4	48,6	49,2	4,5	4,5	9,3	9,2	5,6	5,9	11,5	12,0
Talkito	6,3	6,5	49,2	47,2	2,9	3,2	6,0	6,9	6,1	5,4	12,4	11,4

Table 30. pH, fat and protein in oat base of selected varieties (second series)..

	pH		NIR % DM		NIR % fat		NIR fat % of DM		NIR % protein		NIR protein % of DM	
	Ø	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**	**Ø**	**K**
Scotty	-	6,4	-	47,7	-	2,4	-	5,0	-	4,2	-	8,8
Sonja	-	6,4	-	47,4	-	3,0	-	6,3	-	4,8	-	10,1
Active	-	6,5	-	46,2	-	3,3	-	7,1	-	5,4	-	11,7
NOS Conrad	-	6,5	-	45,9	-	2,6	-	5,7	-	4,2	-	9,2
Oliehavre	6,4	6,6	50,4	49,6	5,0	4,5	9,9	9,1	5,9	6,3	11,7	12,7

Foamability, oat base

The first test of the oat bases produced shows medium foamability in all varieties at both cool conditions and hot temperature. See Table 31.

Interpretation of foam test: below 255 ml = poor, 255-305 ml = medium, above 305 ml = good foamability

Table 31. Foam test at low temperature and at high temperature, first round of analyses.

	Cold 20°C (ml)		60°C (ml)	
	Ø	**K**	**Ø**	**K**
Scotty	280	280	300	295
Fatima	295	310	300	330
Sonja	295	300	325	290
Active	265	285	270	310
Merlin	280	275	290	270
Elison	285	285	305	280
Nemesis	295	295	285	310
NOS Conrad	290	285	275	310
OlieHavre	290	305	290	305
Talkito	280	295	315	280

In the second round of analyses, the tested varieties also did not show good foamability above 305 ml; they all lie in the range of medium foamability. See table 32.

Table 32. Foam test at low temperature and at high temperature, second round of analyses, selected varieties.

	Cold 20°C (ml)		60°C (ml)	
	Ø	**K**	**Ø**	**K**
Scotty		260		285
Sonja		270		245
Active		265		300
NOS Conrad		270		285
OlieHavre	260	255	265	280

Volatile components in oat base

Technological Institute has observed many volatile compounds in selected oat bases that can potentially affect the sensory properties of the oats. Threshold values from the literature (organoleptic threshold) have been inserted in the middle column of Table 33. At higher contents than threshold values, there is a possibility of sensory changes. As can be seen from the table, more volatile components have been observed in the Scotty variety in particular. In the references on the far right in Table 33, which originate from Döhler's own production, there are very few aldehydes that can cause a bad taste. Heptanal in particular gives a rancid aftertaste and is undesirable in the oat base.

Table 33. Volatile components in oat base, ppm. Colour scale: high values red, mid-range values yellow, low values green. ND = not detected.

Irup xod	Fdv#qr	Q dp h	**Class**	**Flavor**	**Organoleptic threshold ppm**	N4#Vfrww|	N6#Vrqmd	N7#Dfwlyh	N;# QRV#Frqudg	#N<# Rdhkdyuh	ö<# Rdhkdyuh	rdw#v|uxs# 934978	rdw#v|uxs# <76645
						dyhudjh#kh{dqdo#htxlydohqwv#ssp							
F5K7R	:803:03	Dfhwdoghk|gh	Doghk|ghv	Juhhq#ohdyhv/#iuxlw|/#urwwhq#dssohv	58	3/346;	3/3533	3/338<	3/33;<	3/347<	3/343<	3/379:	3/3839
F5K9R	9704:08	Hwkdqro	Dofrkrov	Vwurqj#dofrkrolf#hwkhuhdo#p hglfdo	433	3/3639	3/35;4	3/34;6	3/3478	3/33:8	3/3447	3/3383	3/337<
F6K9R	9:09704	Dfhwrqh	Nhwrq	Vz hhw/#iuxlw|/#hwkhurxv/#sxqjhqw/#juhhq#dssoh/#iuxlw|	3170441:8	3/36;<	3/3<49	3/388:	3/37:8	3/38<8	3/379<	3/54<7	3/46:5
F7K;R	:;0;705	Sursdqdo/#50p hwk|o0	Doghk|ghu	Sxqjhqw/#ydu qlvk/#iuxlw|	313348	3/3354	3/335:	3/334:	3/3343	3/3348	3/3346	3/33<9	3/33:8
F7K9R5	7640360;	5/60Exwdqhglrqh	Nhwrq	Exwwhu0vfrwfk#srsfruq/#vwurqj/#exwwhu/#vz hhw#fuhdp |/#sxqjhqw#fdudp ho	3148	3/3454	3/343;	3/339;	3/338;	3/33;6	3/33:8	3/35<6	3/36<3
F7K;R	4560:50;	Exwdqdo	Doghk|ghv	Sxqjhqw/#dssoh0olnh/#p dow	3134031 4	3/335:	QG	QG	QG	QG	QG	QG	QG
F8K43R	44309506	Shqwdqdo	Doghk|ghv	Vwurqj#dflug/#sxqjhqw#rgru#	3135;	3/3399	QG	QG	3/3356	3/335;	QG	QG	QG
F9K45R	9905804	Kh{dqdo	Doghk|ghv	Shdfk/#juhhq|/#sxqjhqw#iuxlw|/#juhhq#judvv	318031k	3/3599	3/3376	3/3377	3/3375	3/33:7	3/3374	3/334<	3/3355
F:K47R	4440:40:	Khswdqdo	Doghk|ghv	Yhu|#vwurqj/#idww|/#kduvk/#sxqjhqw#rgru#dqg#dq#xqsohdvdqw#idww|#wdvw	#313334;#	3/3455	QG	QG	QG	QG	QG	QG	QG
F:K43R	6:::09<06	Ixudq/#50surs|o0	Ixudq	Iuxlw|/#juhhq/#hdwk|	3139	3/3378	QG	QG	QG	QG	QG	QG	QG
F;K49R	45704603	Rfwdqdo	Doghk|ghv	Idww|0rudqjh#rgru/#flwuxv	3133334	3/35:5	3/333<	QG	QG	QG	QG	QG	QG
F:K43R	76460360 8	5/70Khswdglhqdo/#H/H,0	Doghk|ghv	Idww|/#vz hhw#iuxlw|#flwuxv2p hor q#rgru#z lwk#vslfh#qrwhv/#fuhdp |	314	3/539;	3/3348	3/3339	QG	QG	QG	QG	QG
		vxp				3/6;73	3/48<;	3/3<66	3/3;75	3/434<	3/3;55	3/644<	3/5747

Discussion

The aim of the project was to determine if the variety and/or the cultivation method has an influence on the different quality traits of oats and produced oat milk from the same grains. The ten selected varieties represented a genetic variety which resulted in difference among varieties for most quality measures while the cultivation system/location had less of an influence. Quality measures were analyzed in seeds, harvested grain and oat drink base, which gives us the unique opportunity to follow the different varieties and conclude if a quality measure is based on variety if it holds throughout all measurements or if it is more dependent on cultivation and processing.

Cultivation

Due to limitation in number of locations for cultivation it is not possible to separate effects of cultivation system with location specific conditions as soil type etc. So in the following discussion this should be kept in mind when the cultivation systems are mentioned.

The quality measures are of importance for different processes during the live cycle of oats. During cultivation the most important factor is the yield, which was not investigated directly in these trials. Additionally, for organic farming the ability to suppress weeds is important, which was similar for all varieties besides Talkito. Lodging can influence the harvest and also quality parameters, the only variety with lodging issues was Oliehavre, while Scotty and Sonja showed some issues of straw breakage before the harvest but only under conventional cropping.

Dehulling

For the further processing, the dehulling abilities are of high importance. Oats that can be easily dehulled is a desired quality for mills. Thereby it is important that the hulls are easily separated from the grains without damaging the grains in itself. Hullabillty describes the degree of the hulls to come off in standard dehulling procedure. High hullabillty is an important factor for oats for consumption as well as a low percentage of hulls on weight basis of the oat. If the dehulling is more difficult there is the need to use more force during the process, which can end in more broken and harmed grains. If the oat grains are damaged, they are exposed to oxygen, which may influence the quality of the oats, since it may lead to oxidation of fatty acids. This should be avoided since it may lead to unpleasant rancid taste due to the formation of volatile compounds.

Talkito is a naked oat, and does therefore not need to be dehulled, yet there is still the risk of damage to the grains during harvest and their storage as the hulls protect the grains.

The best results of dehulling were achieved by Merlin, NOS Conrad and Oliehavre with more that 99% of dehulled kernels. The hullability also seems to be higher in the conventional cropping system/location compared to the organic management/location, while differences between varieties seem to be stable also compared to the seed. This is in line with a larger study done by [1]. The factors influencing the hullability of oats are not clear. White & Watson (2010) showed in their experiments that varieties with larger kernels had a lower hullability, while our results show the opposite. This should be further investigated.

Heat treatment and enzyme inactivation

After dehulling, there is a need to inactivate the enzymes in the oats to deactivate oxidation of fatty acids and ensure storability. This was done in the project on a pilot scale and not the industry standard. It was done with lower temperature (85°C instead for 100°C) and for a longer time than standard procedure. Additionally, the drying period afterwards was longer. The activity of peroxidase, which is used in industry as a marker for enzymes that cause rancidity, showed no activity afterwards. This inactivity is further supported by the fact that the fatty acid composition was assessed as normal by expert evaluation. Yet, we hypothesize that during this step in the processing something went wrong which caused significant off-taste in the kernels/oatbases. As shown in figure 13 below, the peroxidase is only active for a certain time. Afterwards, there is the possibility of the development of volatile compounds, even though peroxidase might be inactive, as our test suggested. Therefore, Hexanal instead of peroxidase was suggested as a better oxidation indicator in a recent study [3].

These resulting volatile compounds can lead to an unusual umami taste that has been detected in the oat drink bases. Our measurements show also, the oat drinks with the most off-taste had the highest content of volatile compounds. Especially, pentanal and hexanal were found to increase the off-taste.

Coming from the sensory point of view, umami like and rancid off-notes can originate from Maillard reaction and lipid oxidation. The longer holding time at lower temperatures during the heat treatment could potentially have caused already some pre-cursor degradation products from proteins and lipids, which contributed later in the process to the distinct off-taste especially after UHT treatment of the base.

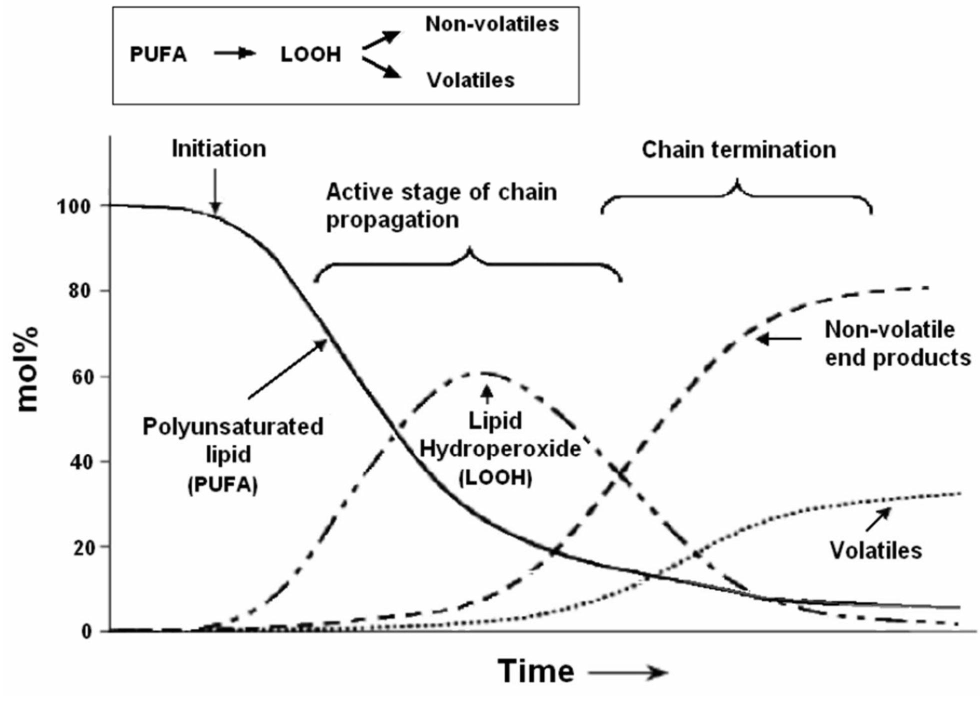


Figure 13: Autooxidation of a polyunsaturated lipid as a function of time showing the various stages in the reaction (redraws from Gardner, 1986)

The heat treatment also influenced the protein-solubility significantly, which was 40-60% lower in the heat-treated grains compared to the seeds. This decrease in protein solubility could be attributed to unusually high protein denaturation during the heat treatment.

This highlights the importance of right processing of oats and the impact small changes can have on the quality of oats. This also implies that the further sensory and performance results from the oat drink base are affected by the heat treatment and the results therefore questionable.

Oat drink production

For the finished oat drink or for an oat drink base, the most important characteristics are taste and for barista foamability. As mentioned, the taste was impaired due to issues during the heat treatment, and we hypothesize, that this was also the case for the foamability since it was generally lower compared to the industry standard. Yet, there were still differences between the cultivars that could be observed. Fatima, Oliehavre and Sonja had the best foaming abilities, which were varieties also rather high in fat and protein content. From our correlation analysis there is also an indication of a positive correlation between fat and protein content and foaming ability. Zhou et al. (2023) also observed positive effects of protein and fat content in oat grains on the resulting oat drink quality. In the literature, the importance of different protein fractions, especially albumins and the general protein solubility is mentioned as determining for the foaming ability, which the results of this project could not reproduce. Yet, prolamin had a significant positive correlation to the foaming ability. During the tasting of the different varieties, it can be noticed that besides some bitter off-notes the sensory analysis of the different varieties stayed true from the grain into the oat drink bases. This indicates these bitter off-notes might be a variety trait or a trait that varieties under certain environmental conditions show.

Comparison of seed and harvested grain

The comparison of quality measures in the seeds and in the harvested grain (figure 14) can give an indication if a trait is based on the variety or more on environmental conditions. Total protein content was dependent on the variety where it was consistently higher and about the same level in the varieties Active, Fatima and Talkito and lowest in Scotty. The protein solubility was noticeably higher in the seeds compared to the harvested grain in either cultivation system/location possibly due to the heat treatment of the kernels. However, some patterns could be seen as well. Throughout all different solubility tests, Scotty, Sonja, and to some extend Nemesis showed the highest protein solubility while Oliehavre had consistently the lowest. In contrast, the protein distribution (proteomics) was not dependent on the variety, where we cannot see a clear pattern among the varieties. Here it seems like alfa-Globulin and beta-Globulin did not differ much between varieties and cultivation, while Glutein was in general higher in samples from conventional management.

The total fat content was also mostly dependent on the variety, yet in general the values were higher in the harvested grain compared to the seeds. However, the total fat content in oats normally differs between years within the same variety. Fatima followed by Oliehavre had the highest fat content and also the highest proportion of non-polar fat throughout. Yet it needs to be noticed that the proportion of non-polar fat did not vary as much between varieties and cultivation.

Sensory and chemical analyses

The correlation analysis (figure 15) showed correlations between all different parameters measured in the harvested grain and the oat drink bases. From literature the expectations were, that protein solubility and content as well as fat content will correlate positively with the foaming characteristics of the resulting oat drink, and that different volatile compounds will affect the taste of the oat drinks, either positively or negatively depending on the compound.

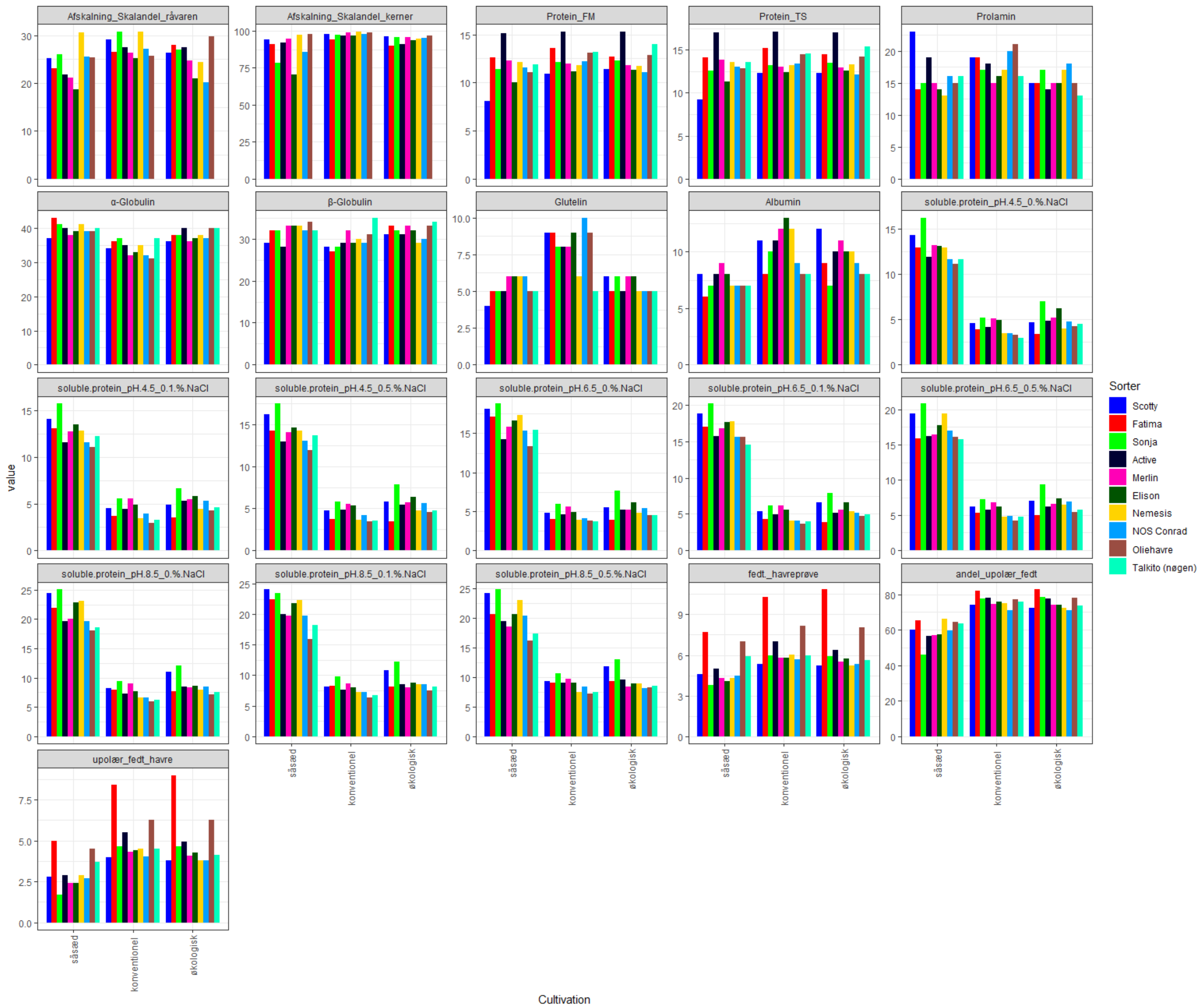


Figure 14. The different colors show the individual varieties. From left to right in each sub-figure, results for seed, conventional and organic samples are shown for a number of different parameters.

Sensory analysis has been done three times throughout the live cycle of the oats, first on seed, then on harvest grains and lastly on the resulting oat drink bases. Since the seeds were of different age, origin and quality, the sensory analysis of them will not be used to determine the varieties quality since the circumstances overwrote the variety effect.

The sensory analysis of the harvested grain and resulting oat drinks, however, correlated positively meaning that the taste of the oat grain apparently also was persistent during the processing. Varieties that had an off-taste as harvested grain also kept an off-taste as oat drink bases. Yet, possibly due to complications during processing and heat treatment of the grains most oat drink bases had a distinct umami off-note flavor.

From the correlation analysis it seems like there are several factors that lead to an off-note taste or counteracted it, yet conclusions based on our very limited dataset need to be made with caution, so

we can only see indications.
The oat grain tasted better when they had a larger kernel size compared to small sizes. Additionally, a high proportion of Linolenic acid in comparison to the other fatty acids lead to an off-note.

For the oat drink bases it can clearly be seen that the off-note taste correlates with specific volatile compounds, specifically pentanal, hexanal, and ethanol lead to a distinct off-taste while acetaldehyde and acetone reduced off-taste.

In general, a high protein and fat content and low pH of the oat drink base correlated with a decrease in the amount of off taste.

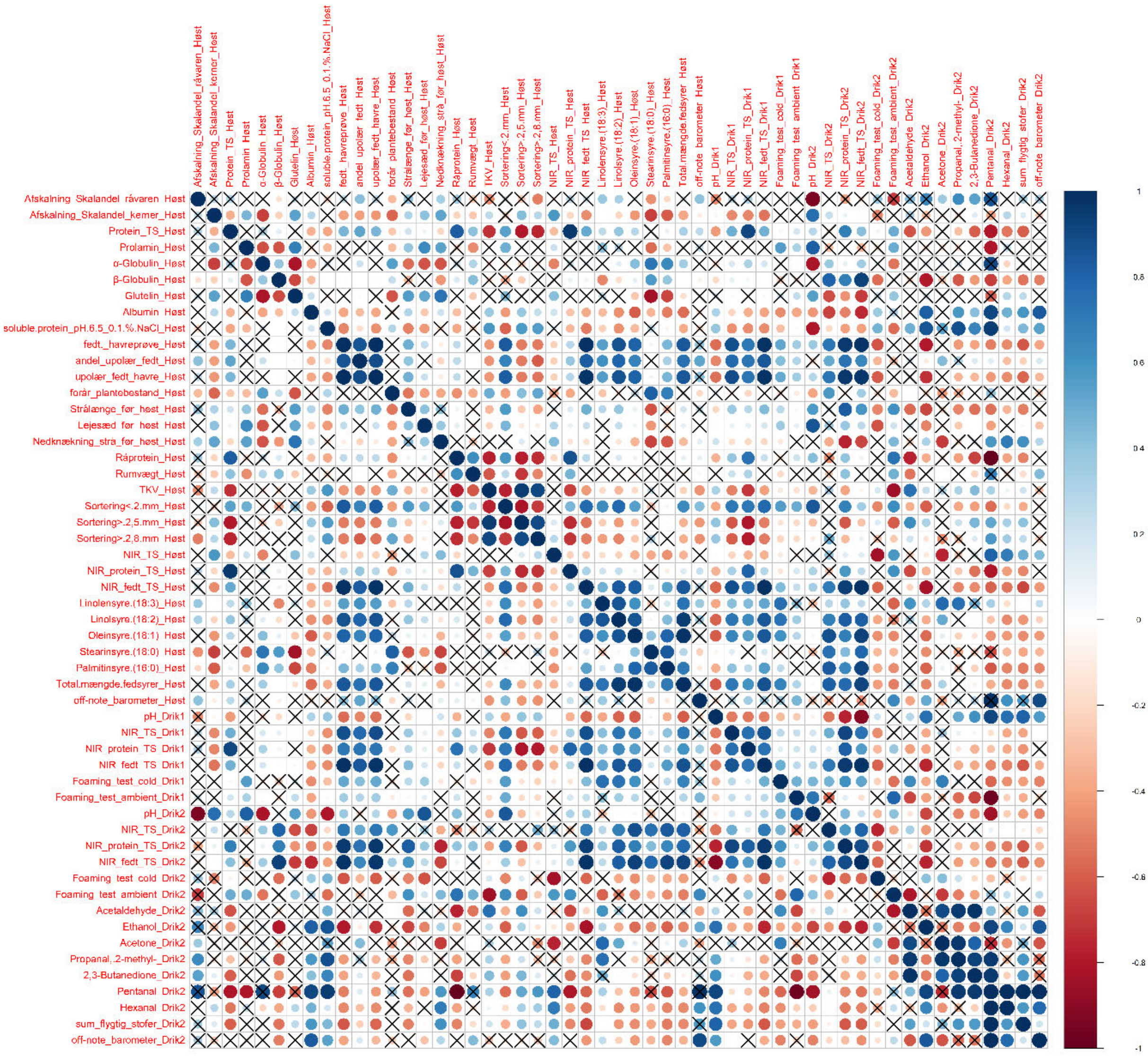


Figure 15. Correlation analysis of all the investigated quality parameters analyzed for the harvested grain (Harvest) and the two different oat bases produced (Drink 1 and Drink 2). The size of the dot and the color intensity show how strong the correlation between two parameters is. If the dot is blue, it means a positive correlation, and if it is red, it means a negative correlation between two parameters. An X marks non-significant correlations.

Another important quality measure of oat drinks is their foaming quality. During the production of oat drink base, two different processes were used. Our results show that, while the foaming test at hot temperature (60°C), the processes do correlate positively with each other, the foaming test at cold temperatures (20°C) does not. In fact, it correlates negatively, meaning the same variety that performed well as drink base 1 does not perform well at dink base 2. This highlights the importance of processing procedures when it comes to oat drink base production. These contrasting patterns can also be seen when looking at the factors influencing the foaming quality. While the amount of free fatty acids, total fat and protein and a high pH content increased the foaming volume in drink base 1 it decreased it in drink base 2.

Conclusion

It is very difficult to draw conclusions based on the limited cultivation and testing set up and unexpected off-taste after processing. What we can conclude is that the variety choice is important in regard to a number of quality parameters in oat in general. And we need to learn more about the effect of these quality parameters on the final quality of oat drink, and which candidates are most suitable for this production.

For the initial productions steps at Valsemøllen it is beneficial with varieties that dehull easily and with low hull content and few kernels under 2 mm in size to increase the amount of raw material. A cautious conclusion based on the correlation analysis is that high protein and fat content are good quality indicators for oat drinks, but for fat content this can also be added as oil during the final processing steps for oat drink. The varieties Sonja, Fatima and Oliehavre has shown the best foamability and a relatively high content of both fat and protein.

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