FINNISH
OAT
ASSOCIATION

The opportunities and risks of the Finnish oats

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1 OAT PRODUCTION AND USE

1.1 Global oat production

Globally, oats are the sixth most cultivated cereal grains after maize, wheat, rice, barley, and sorghum (Fig. 1). Oat production differs from the production of other cereal grains as its cultivation is concentrated in the northern parts of the globe due to the better adaptation to a cool and moist climate. Thus, oats are mainly cultivated in northern parts of America, Europe, and Asia between the latitudes of 35˚ and 65˚. Oats are adapted to different soil types, which makes it suitable for cultivation in areas that are not optimal for other grains.

The annual worldwide oat production has been approximately 23.8 million metric tons (mmt) on average during the market years 2018/2019–2022/2023.[1] The variation between the seasons is rather high, with the lowest production within those five years being 22.2 mmt in 2018/2019 and the highest 25.7 mmt in 2020/2021.[1] Grain yields are affected by environmental factors, such as temperature, seasonal precipitation and seasonal solar radiation, and these factors partly explain the variation between the seasons. During 2012–2021, the five largest oat producers were Russia, Canada, Australia, Poland, and Finland (Fig. 2).

1.2 Oat production in Finland

Oats are the second most cultivated cereal grain in Finland in terms of crop yield (Fig. 3). Over time, the production of oats in Finland has decreased, but over the past 20 years, there has not been major decline in the yields of oats, although some annual variation occurs (Fig. 4).

Compared to other food crops, oats are grown in wider areas in Finland, also including northern Finland. Most of the oats are cultivated in South Ostrobothnia, Southwest Finland, Häme, Pirkanmaa, and Satakunta. Peatlands are relatively common in Finland, and currently about 12% of the arable land is on peatlands – mainly in Ostrobothnia, Kainuu, and Western Finland. Those are rather acidic and nutrient-poor areas, which restricts their use for cultivation. However, oats grow well on this soil

1 Statista (2023a)

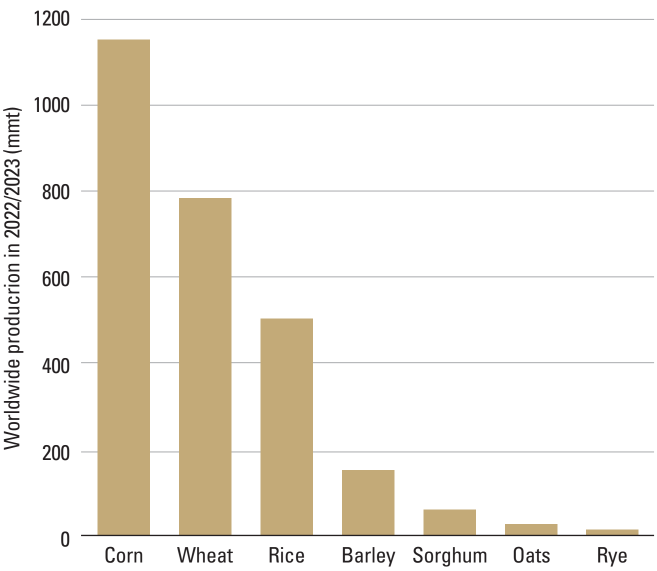


Figure 1. Worldwide production of cereal grains in 2022/2023. Source of the data: Statista (2023b).

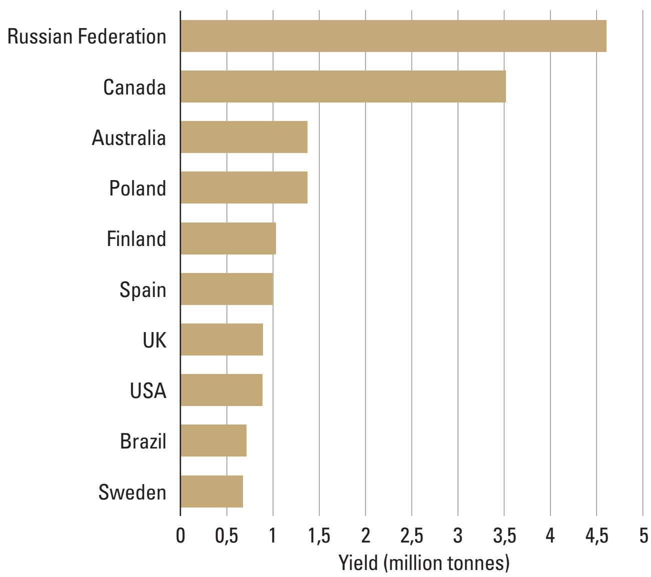


Figure 2. Top 10 oat producers by average crop yield in 2012–2021. Source of the data: FAO, Food and agriculture data.

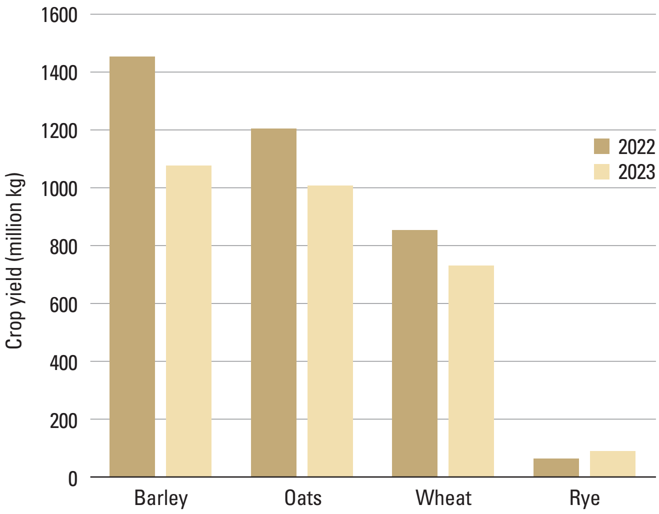


Figure 3. Crop yield of the four major crops in Finland in 2022 and 2023. Source of the data: Natural Resources Institute Finland, statistic publications.

type as they tolerate acidic soil. Additionally, peatlands have high water content, which is beneficial for oat cultivation. The adaptation of oats to more extreme weather conditions and soil types makes it possible to cultivate them in such areas where most other crops are not grown.

In 2023, 74 oat varieties were grown in Finland. According to Finnish Food Authority, ten of the most cultivated varieties (in terms of area under cultivation) were grown in an area larger than 10,000 hectares, and these varieties were Niklas, Avenue, Matty, Meeri, Perttu, Avanti, Avetron, Veli, Belinda, and Benny, starting from the most cultivated one (Fig. 5). Seven of the cultivated varieties were grown in an area smaller than 100 hectares.

In addition to normal oats, organic oats and gluten-free pure oats are also cultivated in Finland. During the past decade, the yield of organic oats has varied between 40 and 107 million kilograms (Fig. 6).[2] The proportion of the total yield remains rather low, but the amount of organic oat production still clearly exceeds the organic production of other crops in Finland, as for example in 2022, the yield of organic oats was 83.8 million kg while the yields for organic wheat, barley and rye were 17.6 million kg, 13.9 million kg, and 12.6 million kg, respectively, according to the Natural Resources Institute Finland.[2] The significance of organic oats, especially in exports, is increasing as already about a third of the exported oats are organic. Organic oats is the largest category of organic foods exported from Finland.

Finland has high potential for exporting oats as the quality, research, and innovations regarding oats are top-level, and Finland is the second largest oat exporter in the world. With the recent oat mill investments, the capability for oat grain and flake export has increased, as the oat production well exceeds the usage volumes of Finland. Currently, even more than 500 million kilograms of oat grains are exported annually, but the amount can still be increased. In addition to normal oat grains and flakes, gluten-free and organic oats are also exported, and the export of organic oats is expected to increase by up to 10% in the near future. However, to further increase the export of oats, the main area for development is highly processed oat products.

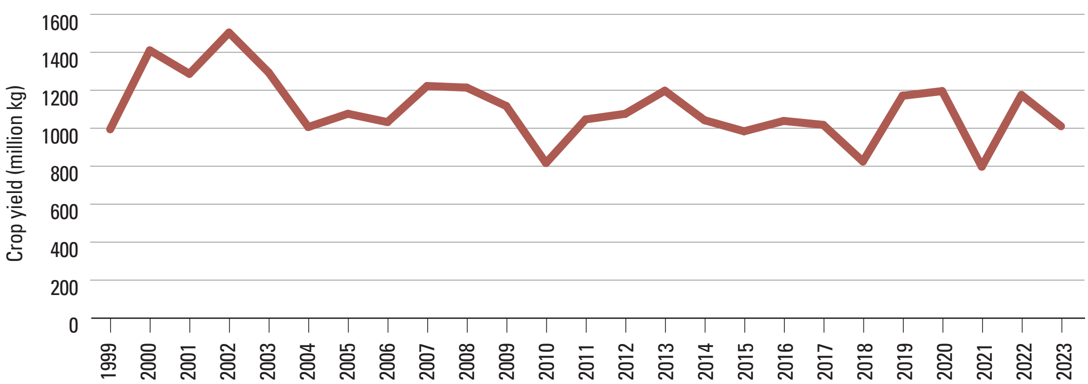
1.3 Oat usage volumes, applications, and market trends

1.3.1 Global use of oats

Still, the majority of oats is used as feed, although the proportion is steadily declining. Globally, the consumption of oats as food is increasing, and in 2020,

2 Natural Resources Institute Finland, statistic publications

Figure 4. Crop yield of oats (incl. organic production) in Finland in 1999–2023. Source of the data: Natural Resources Institute Finland, statistic publications.



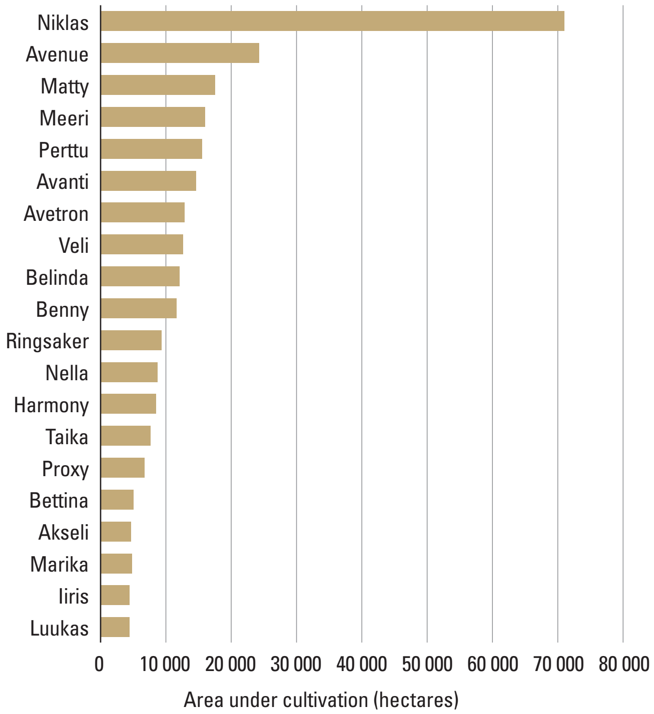


Figure 5. Oat varieties with largest area under cultivation in Finland in 2023. Source of the data: Finnish Food Authority (2023a).

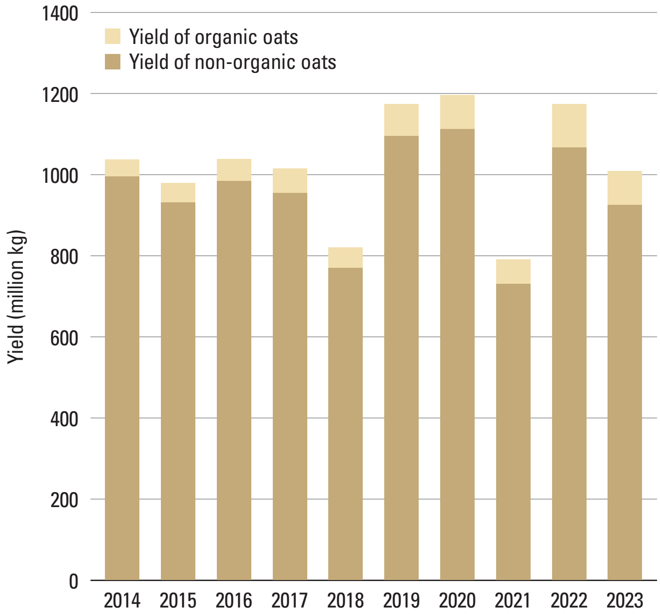


Figure 6. The proportion of organic oats from the total yield of oats in 2014–2023. Source of the data: Natural Resources Institute Finland, statistic publications.

the highest consumption volumes were recorded in Russia (4.3 million tonnes), USA (2.3 million tonnes) and Canada (2.2 million tonnes).[3] Finland had the sixth highest total oat consumption, but per capita consumption was the highest with 192 kg per person.[3]

1.3.2 Oat usage in Finland

In Finland, about 55% of all oats harvested in 2022 were used as feed and 39% for food purposes, according to the responses of the farmers participating in the Finnish Food Authority's grain quality monitoring.[4] Industrial food use of oats has been constantly increasing in Finland during the past decade, and the amount of oats used in the food industry is slowly starting to reach the amounts used by the feed industry (Fig. 7). During the 21st century, the consumption of oats in Finland has tripled.

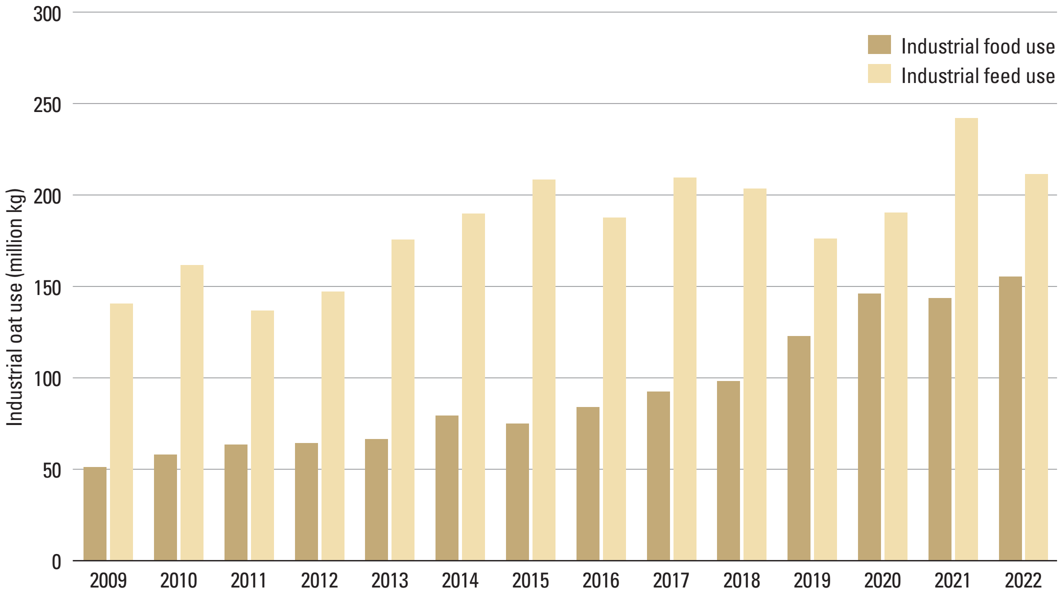
1.3.3 Market development

Plant-based foods are consumed more and more, and consequently the demand for plant-based products is increasing. A similar trend is seen in oat product consumption and demand. The oat market is forecasted to grow at an annual rate of 5.9% from 2022 to 2032, which indicates even more rapid growth of the market when compared to the five-year term from 2017 to 2021 during which the annual growth rate was 4.3%, according to Future Market Insights. The consumption of oats is expected to increase especially in China and India. Of all cereals, oats form about 8% of the market. Organic oats are becoming more significant, as their market is expected to grow by 6.4% annually during the next decade, according to Future Market Insights.

In addition to the traditional oat products, alternative ways to consume oats are searched and new types of oat products are developed. This has led to new types of oat ingredients and highly processed oat products. Different oat ingredients are requested by the industry, and thus oats are nowadays fractionated into different ingredients: starch, fibre concentrates, protein concentrates, and oil, in addition to the more traditional wholegrain flours and flakes. Still, significant growth is expected for oat flour, as ready-to-cook solutions are nowadays ever more appreciated. Also, there is a growing market for processed oat products, such as dairy and meat alternatives. In addition, the demand for quick snacks and on-the-go

3 IndexBox (2021)
4 Finnish Food Authority (2023b)

Figure 7. The amount of oats used by Finnish industry for food use and feed use in 2009–2022 (incl. exported products). Source of the data: Natural Resources Institute Finland, statistic publications.



options is still high, which significantly affects the oat market.

The oat drink market is forecasted to grow at an annual rate of 7.8% during the next decade, according to Future Market Insights. The market for plant-based milk alternatives is large, as about two thirds of the world population are lactose intolerant, although the prevalence varies greatly between different areas. Oat drinks have the benefit of being a more sustainable alternative when compared to dairy milk. FAO and GDP evaluated that in 2015, the emission intensity of dairy milk production was about 2.5 kg CO2 eq. per kg of fat and protein corrected milk, although this number had decreased from the previous estimates.[5] A similar estimate for oat milk varies depending on the source but is generally about one fourth of that of dairy milk. In addition to the smaller greenhouse gas emissions, the water and land use is much less in oat drink production than in dairy milk production. Additionally, oat drinks are considered healthier, which is one reason for the growing demand of oat drinks.

Plant protein ingredients are becoming trendier as consumers are increasingly conscious about the issues regarding their health, environment, and animal welfare. Soybean is often used as a source of plant-based proteins by the food industry, but due to its allergenicity and issues regarding GMO, other alternatives are constantly sought. Compared to other cereal grains, oats lack gluten and have a relatively high protein content and a high-quality amino acid composition, which make oats an interesting protein ingredient alternative. The oat protein market grew by 3.5% annually from 2017 to 2021 and is expected to grow at an annual growth rate of 4.4% from 2022 to 2032, according to Future Market Insights, indicating an accelerating trend. Nordic countries are major players in oat protein ingredient production as both Oy Karl Fazer Ab and Lantmännen are listed as top 5 Market Leaders by Mordor Intelligence.

Oat flour can be further processed into oat protein concentrates by dry fractionation methods or into oat protein isolates by wet fractionation techniques. Isolates have high protein content (more than 80%), but their production is also costly as it requires lots of water and energy. Thus, oat protein concentrates are more often used for industrial scale food production. Compared to some other plant-based protein ingredients, the techno-functional properties of oat proteins are rather limited. The poor solubility at neutral and slightly acidic pH restricts the utilisation of oat proteins in foods. Oat protein ingredients have been and are researched in Finland to find solutions to the poor technological usability, and Finland also has wide knowhow on oat processes and technologies. As a result, innovations relying on oat ingredients have been created, and there is likely more to come. As indicated in the EXPRO white paper[6], one of the

5 FAO and GDP (2019)

6 EXPRO (2022)

major benefits in Finnish innovation culture is the strong collaboration between the different actors including companies, universities, and research institutes.

The production of meat substitutes by wet extrusion is one of the processes where the generally poor technological functionality of the oat protein is not similarly a hindrance. Extrusion process is a feasible process for industrial scale production of meat substitutes from plant-based protein sources. The meat substitute market is expected to grow annually by 10.6% during the 5-year period from 2023 to 2028, according to Statista (2023c), indicating a potential growth for oat-based meat substitute market as well.

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2 OAT QUALITY

The quality of oats is a combination of several traits, and the traits determining the quality vary between different participants of the food oat value chain. Consumers mostly consider factors like healthiness, sensory quality, and cost, but for a miller or food producer, there are often more traits of importance. Food producers might consider attributes affecting the shelf-life and microbiological safety or factors that can be used in marketing, such as health claims and nutritional properties that can be labelled. Millers need to consider the milling yield, but also the potential for different added quality fractions that have functional properties. Breeders, on the other hand, need to consider all the participants of the value chain when forming aims for breeding.

2.1 Oat genome and breeding perspectives

The cultivated oat (the common oat, *Avena sativa*) is located in the tribe Aveneae, which belongs to the subfamily Pooideae (also called Festucoideae) in the family Poaceae (Fig. 8). Other major crops in Finland (namely barley, wheat, and rye) also belong to the subfamily of Pooideae but to a different tribe, Triticeae, which explains some of the differences between oats and these other crops. Avena species include diploids, tetraploids and – as *Avena sativa* (AACCDD) – hexaploids. The genome of oats has not been fully revealed, but recently some new steps have been taken on this road. In 2022, Kamal et al. presented the close relationship of *Avena sativa* and both the diploid *Avena longiglumis* (AA) and the tetraploid *Avena insularis* (CCDD) indicating a probable source of the subgenomes of the common oat. In late 2021, also the Natural Resources Institute Finland published a news piece informing that the whole genome of the Finnish oat cultivar Aslak had been sequenced. With these new advances, the genes of oat and their functions have become more known and therefore there is evermore potential for breeding of new cultivars with the desired traits.

From the late 19th century onwards, oats have been systematically bred. During the past century, cultivation

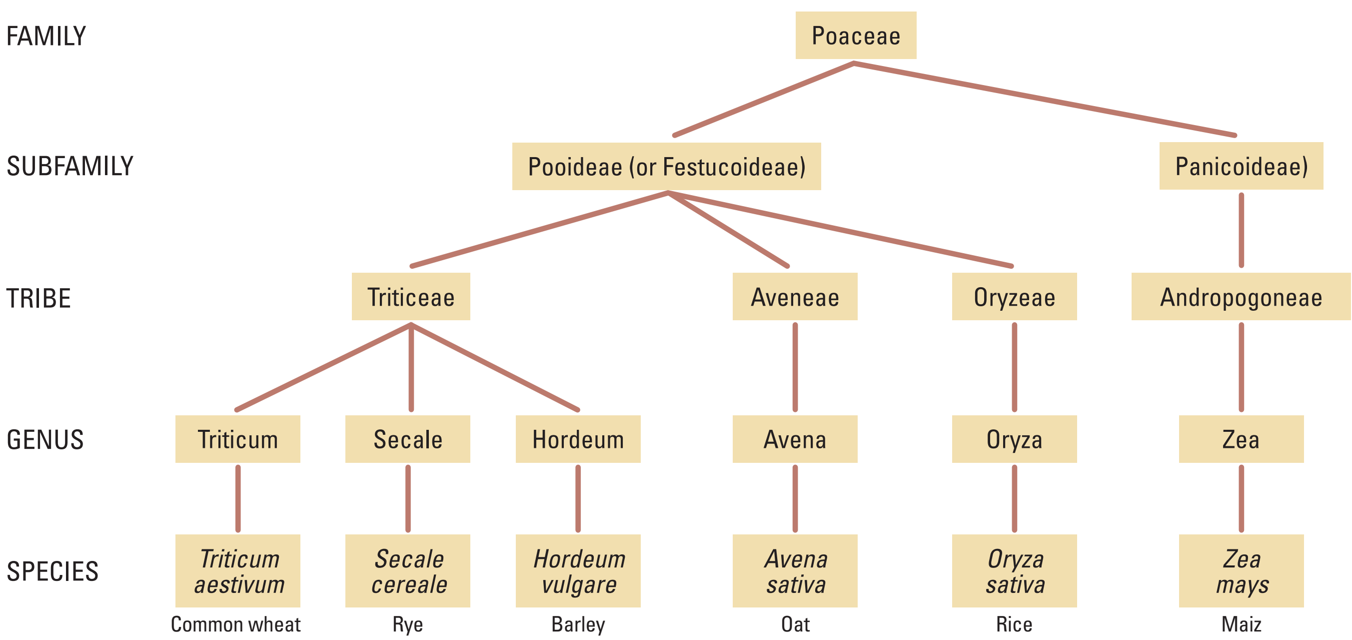

Figure 8. Phylogenetic relationships of some cereal grains.

has gone from genetically diverse landraces towards more uniform cultivars. The breeding of oats has proceeded relatively slowly compared to grains that are globally cultivated more (such as wheat).

As the food use of oats has only recently started increasing, the breeding objectives have mainly been related to the traits related to feed use, such as high grain yield, high protein content, resistance to lodging (influenced e.g. by the straw length), and resistance to diseases. Grain yields have increased by about 40% through breeding, but still the yields of oats are far from those of wheat.[1] Recently, breeding has focused more on traits which ensure the quality of oats from the perspective of different food applications. The significance of grain size has increased, and consequently sieving (to determine the number of grains smaller than 2 mm) has been included in the quality requirements of the export oats. Other factors in which the food industry has been interested are low hull content, light and bright colour, and β-glucan content.

Finland has long traditions in oat cultivation and breeding. As Finnish arctic conditions are different from the conditions of other oat producers, Finland has been forced to breed cultivars that suit its conditions. In addition to these adaptation-related traits, Finnish breeding has also succeeded in improving other desired traits, as reviewed in the next chapters.

2.2 Quality of the Finnish oats

Generally, Finnish oats are light-coloured and have large grains and low husk content. The northern location and the growing conditions that differentiate Finland from most of the other oat producers give some advantages – and on the other hand also disadvantages – to Finland as an oat producer. Finland has extremely good water resources and based on the water poverty index by World Water Council and the UK Centre for Ecology and Hydrology, Finland is considered globally as one of the countries with the best water sufficiency.[2] Additionally, Finland has good air quality and clean soil, which ensure the growing conditions that enable cultivation of good-quality oats. Oats also grow well in acidic soils and peatlands, which are common in Finland.

The cultivation of oats has focused to the northern parts of the globe due to their better adaptation to cool and humid climate compared to the major crops, such as wheat and barley. Oats have adapted to the Finnish conditions – cool weather, short growing season, and long days – as for the growth of oats, warmth is not as crucial as for the growth of other crops. Finland is the most northern location for grain cultivation, and this results in a cooler climate but also longer days, which enable exceptionally fast growth and development of the plant. However, due to the northern location, the cultivars grown in Finland are mostly such that are either tested to suit Finnish growing conditions or specifically bred for these conditions.

The comparatively large fluctuation in weather conditions in Finland is one of the main risks for Finnish oat cultivation. The Finnish summer is often rainy, which causes higher risk for fungal disease by *Fusarium* fungi and deoxynivalenol (DON) mycotoxins. Actions have been taken in Finland to tackle these challenges regarding oat cultivation. In addition to the successful breeding, one major factor in securing oats' storage stability is the drying process taking place at farms, which allows the moisture content of grain to decrease to ca. 14% after harvesting.

Currently there are more than 70 oat cultivars grown in Finland, and this results in high variance in the quality of oats that the mills receive, which is especially seen in fluctuating hectolitre weights and groat sizes of oats. More consistent quality could be achieved by reducing the number of cultivars. However, all cultivars are often accepted by the food industry, as long as they fulfil the quality requirements.

2.2.1 Hectolitre weight

Specific weight remains a significant quality factor, and usually it is measured as a hectolitre weight (mass of grain in kilograms per 100 litres). Finnish oats have relatively high hectolitre weights. Hectolitre weights are dominated by the genetics of a plant variety, but the values can be decreased by environmental factors (e.g., weather conditions, poor nutrition status of soil). In the case of drought or heat, oats aim to decrease the loss of water by closing some of the guard cells. This leads to insufficient amount of photosynthates transported to the developing grain resulting in smaller grains and lower hectolitre weight. Thus, the Finnish cool climate accompanied by long days are favourable for oat cultivation and result in relatively high hectolitre weights in Finnish oats.

1 Webster and Wood (2001)

2 Kurppa et al. (2015)

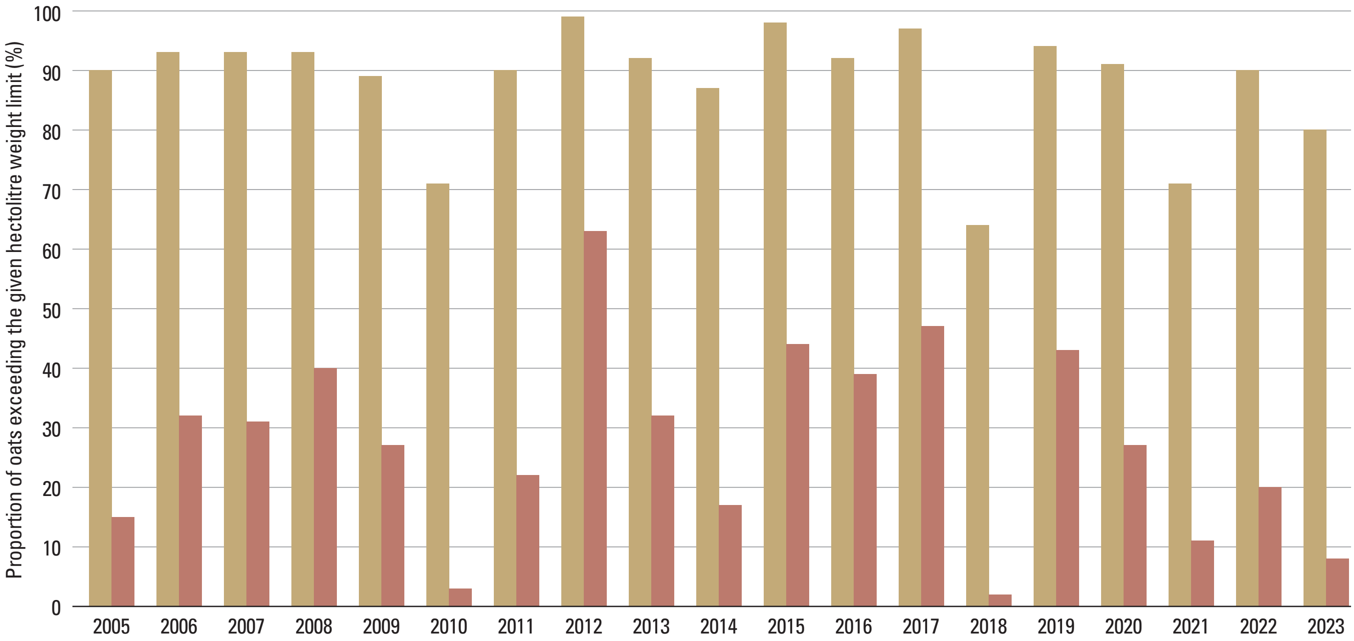

Figure 9. The proportion of oats grown in Finland having hectolitre weight of at least 52 kg (brown) and at least 58 kg (red) in years 2008—2023. Source of the data: Natural Resources Institute Finland, statistic publications.

The hectolitre weight has high heritability, which makes it a relatively easy trait to modify by breeding. Finnish breeders have aimed for increased hectolitre weights especially in the case of feed oats, but hectolitre weight is also considered an important quality trait for food oats. For export, the limit for good-quality oats for food use is considered 56–58 kg in Finland although in other European countries the limit is often set to 54 kg. In the Finnish OatHow project, Finnish oat samples (N=30)[3] were compared with international samples (N=17)[4] and significantly higher hectolitre weights were reported for the Finnish samples as the averages were 59.3 kg and 57.3 kg for Finnish and international samples, respectively.

The Finnish Food Authority is annually analysing and reporting the quality of the Finnish grains. For oats, the reported quality parameters include hectolitre weight, protein content, amount of small grains, and amount of DON. The Natural Resources Institute Finland is annually reporting the quality of the grain harvest by compiling data collected by both the Natural Resources Institute Finland and the Finnish Food Authority. For hectolitre weight, 52 kg is considered aimed minimum for the feed oats and 58 kg aimed minimum for the food oats, and the proportion of oats exceeding this 58 kg hectolitre weight varies largely from year to year (Fig. 9). When observing the above-mentioned quality traits between different oat cultivars, there is large variation. For example, in 2022, the average hectolitre weights varied from 54.2 kg in cultivar Niklas to 58.3 kg in cultivar Iiris within the tested 17 cultivars.[5]

3 Jokinen et al. (2021)

4 Unpublished results from public report of the OatHow project

2.2.2 Grain size and groat content

Both the grain size and groat content are important quality factors for food oats. Regardless of the low value of oat hulls, naked oats are not often cultivated in Finland as they are, for example, more susceptible for pre-harvest sprouting and quality defects (e.g., by pests or those caused during harvesting). Thus, groat content and hullability (ease of dehulling) are traits that significantly affect the quality of Finnish oats.

When breeding was focusing more on the quality aspects for feed use, grain size was not paid much attention to. However, for food use, the grain size is an important attribute. Large grains, and consequently large groats, are desired for flaking purposes, as the groat size directly determines the maximum size for the flakes.

5 Finnish Food Authority, open information database

Additionally, larger sized grains are preferred by millers, as those also result in better milling yield and can be dehulled with slower rotor speeds in an impact dehuller. When the food use of oats started to increase, oat breeding in Finland began to aim for larger grain size. For sieving, the length of the grain is not the only important factor, but more the width of the grain. Thus, breeding has been aiming to provide varieties with shorter and thicker grains. During the growth of the plant, grain filling is affected by the location and amount of the kernels in the panicle and the amount of available photosynthesis products. The final grain size is influenced by this grain filling stage and its length, as well as genetics.

Finnish oats have large groats, which also decreases the ratio of hulls to groats. These are both beneficial especially for milling. Large groats of Finnish oats are a result of both the successful breeding and growing conditions. The long days during summer promote the growth of the main stem and the majority of the oats harvested in Finland are from those. Additionally, the oats in Finland are cultivated with high plant density, which also boosts the growth of the main stem. The groats in the main stem are larger than in tillers resulting in an overall larger groat size in Finnish oats. Generally, the hull content of oats is about 25% on average, but contents up to 36% have been reported.[6] Compared to these estimates, Finnish cultivars have relatively low hull contents, as in Natural Resources Institute Finland's official variety trials 2016–2023, the average hull contents were below 23% in all of the tested Finnish cultivars.

Usually, from the quality perspective, the most commonly measured property is the amount of small grains determined as the amount of shrivelled grains (<2.0 mm in sieving), which should not exceed 10% in the case of food-grade oats. According to the official variety trials of the Natural Resources Institute Finland, none of the tested (N=47) varieties exceeded this percentage in 2022. The average amount of small grains (<2.0 mm) in oats cultivated in Finland has exceeded 10% only once within the last decade, in 2021 (Fig. 10).

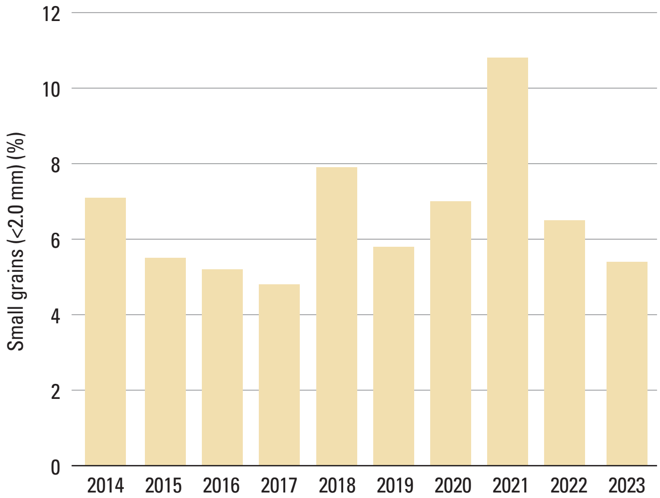

Figure 10. The average amount of small grains (<2.0 mm) (%) in oats grown in Finland in 2014–2023. Source of the data: Finnish Food Authority, open information database.

2.2.3 Colour

Finnish oats have a light and bright colour, and the Finnish breeding knowhow has had a key role in achieving this. Groat colour and the consecutive colour of the oat ingredients is a factor to be considered in the breeding of oats, as consumers tend to find light-coloured oats more appealing. Light colour was one of the most selected attributes when studying sensory characteristics that affect the pleasantness of oats with CATA (cross all that apply) analysis both in Finland and in China, indicating that this attribute is appreciated in countries with varying food cultures.[7] Also, dark grain colour is often connected to quality defects, and thus both hulled grains and groats are preferred with light colour. However, these two colour-related traits seem not to correlate, as groat colour varies significantly within oats with similar hull colour.[8] Oat grain lightness also correlates with some other quality traits, such as protein content (positive correlation) and starch content (negative correlation) of the flour, and thus colour can be considered an important quality indicator.[9]

2.2.4 Plant diseases and pests

Plant diseases and toxins

In Finland, the moisture percentage of the grain at threshing is usually higher than in most European countries, resulting in a need for drying of the grain. This drying ensures the stability of the grain during storage. However, depending on the weather conditions

6 Webster and Wood (2011)

7 Laaksonen et al. (2020)

8 Ames (2014)

9 Jokinen et al. (2021)

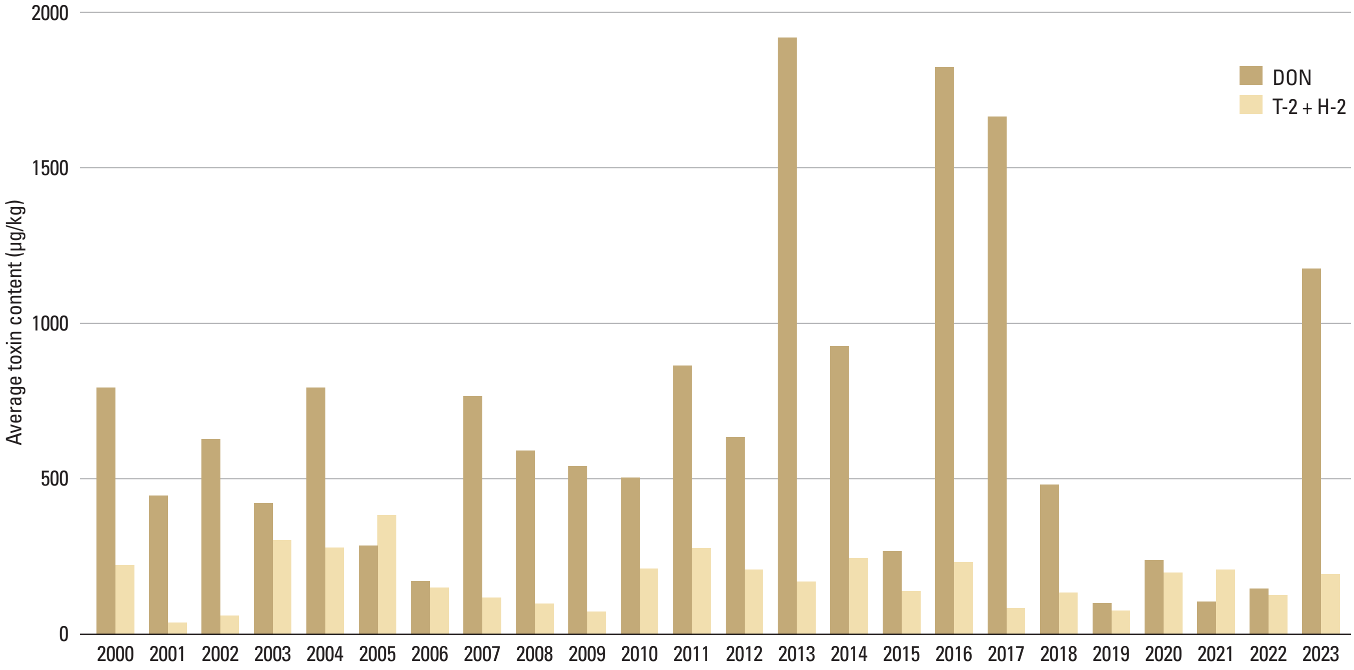

Figure 11. The average DON and T-2 + HT-2 contents (µg/kg) of oats in 2000–2023.
Source of the data: Viljan turvallisuustietoseuranta 2023 (unpublished).

during the growing season, moulds and mycotoxins are a risk factor to be considered, and the importance of this is only increasing as Finnish weather conditions are becoming more optimal for the growth of certain fungi. The most relevant mycotoxins for Finnish grains are the toxins of *Fusarium* fungi: deoxynivalenol (DON), T-2 and HT-2 toxins and zearalenone (ZEN). For example, for the accumulation of DON, the most optimal conditions are a rather dry early summer and more rain towards the end of the growing season, which indeed matches with the typical Finnish weather.

From 1999 onwards, the safety of the Finnish grain has been systematically evaluated involving an annual comprehensive analysis of the mycotoxins in Finnish grains. This has provided more information and consequently is resulting in better predictions and controlling of the toxin levels in grains. Legislation indicates limits for the amounts of DON and ZEN in food-grade oats: 1750 µg/kg and 100 µg/kg, respectively. Mostly, the DON contents of the Finnish grains have been below the limit values, but still annually some samples exceed the limits, and these increased values are found especially in oats.[10] The average DON content in oats has mainly been well below the limit, but some problematic years have occurred, as shown in Fig. 11. For T-2 and HT-2 toxins, the EU currently gives only a recommendation (2013/165/EU) regarding the maximum toxin level in food-grade oats (1000 µg/kg). Compared to this recommended limit of both of these toxins, the average sum of T-2 and HT-2 toxins in Finnish oats has been low in 2000–2023 (Fig. 11).

In addition to other means to decrease the *Fusarium*-related disease called Fusarium head blight (FHB), breeding of more disease-resistant varieties is in a key role. Some oat varieties with decreased mycotoxin accumulation have already been bred. However, breeding oat varieties with more resistance using traditional methods takes relatively long, and thus new tools for breeding are needed. In Finland, a new genomic selection tool has been developed to be able to breed more quickly and accurately oat varieties with better resistance towards FHB.

Pests

For Finnish oats, the most significant pests are cereal leaf beetle (*Oulema melanopus*), species in *Phyllotreta* genus and bird cherry-oat aphid (*Rhopalosiphum padi*). Cereal leaf beetle usually requires the use of pesticides only if the summer is exceptionally warm in Finland, but normally it does not cause damage for Finnish oats. Both the cereal leaf beetle and the species of Phyllotreta genus tend to eat

10 The Finnish Cereal Committee (2015)

holes to the leaves of the plant, decreasing the area available for photosynthesis. The bird cherry-oat aphids are the most common aphids in cereal grains, and they cause damage especially to barley and oats. They suck sap from the plants and thus decrease the energy available for the growth of the plant. Thus, these pests can result in a decreased yield (20–30% reduction).

Finnish conditions are optimal for growing healthy oats. The cold winter reduces the amount of plant diseases and pests in the soil and additionally, the shorter growing season leaves less time for pests to act. Thus, in Finland, the need for pesticide use is lower than in most other oat-producing countries and the risk for pesticide residues is low.

2.2.5 β-glucan content

β-Glucan is the most abundant non-starch polysaccharide in oats. The European Food Safety Authority has approved health claims for cholesterol-lowering and blood glucose-attenuating effects of β-glucan, and this has resulted in β-glucan content rising to one of the breeding aims. One way to increase β-glucan content in oats is crossbreeding. In 1998, a study revealed β-glucan concentration to be controlled by at least two or three gene pairs.[11] About a decade later, Finnish researchers did gene mapping of a cross between the Finnish cultivar 'Aslak' (high β-glucan content) and the Swedish cultivar 'Matilda' (moderate β-glucan content) and showed two chromosomal regions which affected the β-glucan content of oats.[12]

When Finnish oat samples (N=30)[13] were compared with international oat samples (N=17)[14] in the OatHow project, the Finnish groats were shown to have lower β-glucan contents (5.2% and 6.3% on dry matter basis on average, respectively). However, these cultivar samples were not selected focusing on the β-glucan content. In these samples grown in Finland, β-glucan content ranged from 3.6% to 6.7%, indicating rather high maximum contents in some samples when comparing this for example to the range reported by Herrera et al. (2016) in eight varieties grown in different locations in Canada (4.37%–5.82%). In a study by Zute et al. (2011), 42 Latvian husked cultivars were compared with 40 international husked cultivars, and out of the international cultivars, the highest β-glucan contents (in grains with husks) were found in cultivars of Nordic origin: breeding line Bor 88322 from Finland and cultivar Freja from Sweden both had β-glucan content of 34.1 mg/100 g of oat grains (on dry matter basis) when calculating the average of three years (2007, 2008, 2009), but the Finnish cultivar had less variation between the different years. Indeed, some high β-glucan content cultivars (such as Taika and Peppi) have been bred in Finland and these often also contain relatively high protein content.

2.2.6 Gluten-free oats

Celiac disease is an autoimmune disease in which the gluten proteins of wheat, barley, and rye cause inflammation in the small intestine, and thus this disease requires a life-long avoidance of gluten proteins in the diet. The prevalence of celiac disease is about 2% in Finland. Additionally, there are persons following a gluten-free diet for other reasons, such as gluten sensitivity. In total, 4.6% of Finns were following a gluten-free diet in 2014.[15]

According to Codex Alimentarius Standard for foods for special dietary use for persons intolerant to gluten (CXS 118 – 1979, revised in 2008), oats can be tolerated by most of the gluten intolerant persons and thus the inclusion of oats in the diet of gluten intolerant persons can be determined on national level. In Finland, oats are considered gluten-free and can be consumed by persons suffering from celiac disease, if the oats are so-called pure oats and not contaminated by gluten-containing crops (wheat, rye, or barley) at any step of the production chain.

The cultivation of pure oats should aim to produce oats without any contamination by other crops. However, mills usually accept batches with maximum 4–6 foreign grains per kg of oats, in which case the limit for gluten content in gluten-free products (20 mg/kg) is not yet exceeded. Pure oats can be produced either by excluding all the gluten-containing grains from the crop rotation or by including those, but inhibiting contamination by other means (e.g., careful cleaning of the machinery and considering the threshing order).

11 Kibite and Edney (1998)
12 Tanhuanpää et al. (2007)
13 Jokinen et al. (2021)
14 Unpublished results from public report of the OatHow project

15 Helldán and Helakorpi (2015)

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3 CONSUMER INSIGHTS

3.1 Image of the oats

Oats are generally seen as a healthy and sustainable ingredient. Industry reports indicate that the recent surge in the interest in oat products is, in large part, due to oats' image as a sustainable alternative.[1] Consumer awareness about environmental issues has risen considerably and increasingly affects the choices that they make. For example, in the plant-based milks sector, almond and soy suffer from a poor environmental image due to issues related to water-intensive cultivation and deforestation, which has pushed consumers to shift to oat-based alternatives, which are perceived as more environmentally friendly. In the UK, oat milk overtook almond milk as the most consumed plant-based milk in 2020 and in the US, it has surpassed soy milk as the second most consumed plant-based milk. [2, 3]

Oat also has a somewhat unique reputation a particularly healthy grain. Consumers especially construe oatmeal as a healthy food – a reputation which may carry over to other oat-based products. According to Mintel's market research, consumers are increasingly looking for healthier options, which has boosted the sales of plant-based products.2 However, there is potential to strengthen the healthy image of oats, especially in markets where oat is not traditionally consumed. In particular, more consumer education is needed regarding the specific health benefits of oats, such as lowering blood cholesterol levels.

3.1.1 Finnish oats

Finland is generally seen as a producer of clean, safe, and high-quality foods with sustainable and ethically sound production practices. This profile aligns well with the global trends of sustainable and healthy foods. Finnish oats are particularly known for their high quality and safety on the international market.[4] Consumers generally perceive Finnish foods as pure, clean, and natural, but it is doubtful whether Finnish oats in particular would evoke any specific associations. Internationally, consumers might be more familiar with the broader category of "Nordic" foods, which are, in a similar vein, considered healthy, fresh, and natural. Such an image is especially beneficial for oat, as it is favoured by health-conscious individuals. It should also be noted that domesticity of foods is highly valued in Finland, which likely results in a positive affect to Finnish oats among Finnish consumers. However, in some other markets, such as China, imported foods are often preferred due to better perceived level of hygiene and safety, for example.

Moreover, Finland is one of the leading countries worldwide in terms of oat innovations and research. This long tradition has resulted in strong technical expertise in oat processing in the country and facilitated the development of a multitude of novel oat products. Exporting these products strengthens the brand of Finnish oats internationally and increases their visibility on the market. Although the export value of Finnish oat products has been steadily rising, especially through oat flakes and added-value products, there is still work to be done to increase consumer awareness. It is crucial for Finland to maintain its reputation as a producer of high-quality oats with a high level of expertise to ensure competitiveness on the international market.

3.1.2 Gluten free oats

About 1% of the global population is estimated to suffer from celiac disease, and the only treatment is adhering to a strict gluten-free diet. The status of oat as a gluten-free crop has been a matter of some debate, although the overwhelming majority of studies support its suitability for most celiac patients, given that the oat material is free from gluten-containing contaminants.[5] However, oat has not traditionally been recommended for celiacs, which has undoubtedly influenced consumer perceptions. In

1 Tetra Pak (2022)
2 Mintel (2021)
3 Statista (2023b)
4 Kurppa et al. (2015)
5 Smulders et al. (2018)

fact, it is not clear how well consumers are aware of the gluten-free status of oat. The availability of both gluten-free (pure) and non-gluten-free (contaminated) oats on the market further complicates the issue from the consumer's perspective. However, oats would be a highly valuable addition to the gluten-free diet, which is often insufficient in many nutrients, particularly fibre.

There is a growing interest for gluten-free foods among non-celiac consumers as well. The global market value for gluten-free foods is projected to double in the next ten years.[6] Motivations for adopting a gluten-free diet include perceptions of improved health condition, well-being, and prevention of disease, among other factors. The gluten-free diet is also a lifestyle trend, advocated by some social media influencers and celebrities, which has contributed to its popularity. This surge in interest presents an opportunity for oat products, but consumer education is needed to solidify oats' role in the gluten-free diet.

3.2 Consumption habits

Oats are most popularly consumed as porridge or as ready-to-eat (RTE) products, such as muesli or cooked breakfast cereals. Consumption habits vary by country: RTE cereals are popular in Europe, while in the United States, oatmeal dominates the market.[7] Oat consumption per capita is highest in the Nordic countries, the UK, and the US. Consumer interest in oat has grown significantly in recent years, evidenced by an extraordinary increase in consumption even in some established oat-consuming countries. In Finland, for example, per capita consumption of oat has more than doubled in the past ten years, rising from 5.4 kg in 2012 to 10.9 kg in 2022.[8] This increase is fuelled by the surge of novel oat products in the market, such as meat alternatives and plant-based milks; the latter is the biggest driver of growing oat demand globally. Minor applications for oats include bread and pasta, among others.

3.3 Factors influencing consumer acceptance of oat products

3.3.1 Sensory properties

Numerous studies have indicated that sensory properties are a key determinant of food acceptance and food choice.[9] Although consumers may have intentions of selecting healthier or more sustainable options, actual food choice is likely to be heavily influenced by taste, in addition to other factors such as convenience and habit. Therefore, the hedonic response elicited by a food product must always be the primary focus in new product development. Even with functional foods, which are especially targeted for health-conscious individuals, most consumers are unlikely to compromise on taste in exchange for the health benefits. This is an important consideration for oat-based products, which are often seen by consumers – and intentionally marketed – as a healthy and sustainable alternative. Changing the consumption habits is unlikely to be successful only by promoting the environmental or health benefits of oats. Instead, the products should be modified to be more hedonic by improving their sensory properties.

In terms of flavour, oat is usually described as being mild and pleasant, with a slight toasted aroma originating from the heat treatment (kilning) applied during milling. Kilning largely inactivates endogenous enzymes which would otherwise make oats highly susceptible to rancidity development, leading to unpleasant off-flavours. Still, the sensory acceptability of oat-based foods is often a challenge, which can be partly attributed to the inadequate technological functionality of its components. In baked goods, the absence of gluten results in products with lower volume and inferior structure compared to wheat-based products, reducing their acceptability. However, as discussed in the next section, consumer acceptance of such products is highly influenced by culture. In Finland, oat bread and other non-wheat breads are very popular, but this is not the case in most other countries. The technological functionality of oat protein is also rather low compared to soy or pea protein for example, which reduces its applicability in products such as meat alternatives. The functionality may be improved by enzymatic treatments, as shown by some recent studies.[10] Considering the importance of sensory properties in affecting food choice, much research is still needed on improving the functionality of oat components to facilitate the production of oat-based foods with high consumer acceptance, and to diversify the potential applications for oat.

6 Statista (2022)
7 Business Finland (2022)
8 Statista (2023a)
9 Verbeke (2006)
10 Immonen (2023)

3.3.2 Familiarity

Although sensory properties are paramount, familiarity and expectations also play a major role in consumer acceptance of plant-based products. Studies have shown that consumers prefer foods that are familiar to them, and familiarity is often closely linked to culture. Although consumption of oats is common in Finland and other Nordic countries, globally it is still a minor crop in food. In a study conducted on Finnish and Chinese consumers, ethnicity significantly influenced the hedonic ratings of various oat-based products, which was linked to differences in familiarity due to traditional consumption habits in different countries.[11] Consequently, introducing traditional or novel oat-based products might be more challenging in markets where oat is not part of the traditional diet, and thus requires careful analysis of the targeted consumer segment as well as consumer education about the health benefits of oats. On the other hand, growth potential is high in non-traditional markets, like many Asian countries.

Novel foods such as plant-based milks and meat analogues are still relatively unfamiliar to consumers, which poses a further challenge. In the consumers' minds such products are compared to the products they are trying to mimic, and any deviation from the expected sensory properties is likely to negatively influence their acceptance. It is worthy to note that plant-based alternatives are not necessarily always designed to exactly mimic the corresponding animal-based foods, but in the consumers' minds they are nevertheless positioned in the same category. Consumers can also be classified based on their level of food neophobia – aversion of unfamiliar foods. Jaeger and Giacalone (2021) found food neophobia status to be a significant barrier to consumption of plant-based milks but noted that neophobes might not avoid these products because they are plant-based, but simply because they are unfamiliar. Similar results have been obtained regarding meat alternatives. Food producers should be aware of these issues, especially considering that oat is being increasingly used in novel formulations.

3.3.3 Health interest status

Choosing to adopt a healthy diet is an important driver for oat consumption. Studies have shown that concern about negative health consequences of consuming animal-based foods is one of the primary reasons among consumers to increase the intake of plant-based foods. Individuals with a high level of health interest may also be more likely to accept lower palatability in exchange for the perceived health benefits. Considering the healthy image of oats, health-conscious consumers are an obvious target for marketing. Although the interest in healthy eating has increased, consumers are divided in the attributes that they value, which has implications for consumption. Multiple studies have indicated that consumers who value health, sustainability or ethical issues are more likely to be users of plant-based milks, while taste and nutritional value are more important for dairy users.[12],[13] It can be argued that development and marketing of plant-based alternatives should be targeted towards non-users, meaning that efforts should be directed towards improving the sensory and nutritional properties; emphasizing the health or sustainability aspects is unlikely to attract new consumers.

3.3.4 Health claims

Oats contain a high amount of β-glucan, which has accepted health claims in the EU. A 2007 study showed that β-glucan health claims provide additional value to consumers: when the health claim was present, consumers were more willing to use the products and willing to pay a higher price.[14] Health claims may also elicit a "halo effect", whereby the presence of a health claim causes consumers to rate the product higher also on aspects unrelated to the claim. However, the exact wording of the on-pack claim should be carefully considered to maximise consumer response. Interestingly, more medical sounding health claims may be preferred, as these are seen as more credible. Many consumers might not be aware of the physiological effects of oat β-glucan, and it is therefore advisable to precisely convey the associated health benefits – more general nutrition claims such as "high in oat fibre" might not be as effective. On the other hand, adding too much information may compromise consumer understanding of the claim.

Despite the potential, the use of health claims related to β-glucan in food products globally remains limited. A

11 Laaksonen et al. (2020)

12 McCarthy et al. (2017)

13 Halme et al. (2023)

14 Lyly et al. (2007)

possible challenge is meeting the eligibility criteria for the use of the claim, such as β-glucan quantity per serving (e.g., 1 g in the EU). This is especially true for products formulated as a mixture of cereal ingredients, highlighting the need for oat cultivars with high beta-glucan content. In addition, it is equally important to educate consumers about the health benefits of β-glucan to promote consumption. Some studies have questioned whether consumers can understand or even pay much attention to on-pack health claims. The presence of claims may even deter some consumers due to reduced expectations on other attributes such as taste (negative halo effect). However, consumer responses vary significantly depending on the exact claim, which likely explains some of the discrepancies in the literature regarding the effectiveness of claims. In general, health claims that are familiar, understandable, and credible are more likely to elicit a positive response.

3.3.5 Naturalness

Naturalness of food is valued by the majority of consumers across different cultures, and it strongly affects acceptability.[15] Naturalness is a vague concept which consumers variably associate with attributes such as healthiness, sustainability, lack of additives, and minimal processing. Although naturalness is hard to define, what matters from the food producer's perspective is the perceived naturalness, that is, how consumers intuitively see the product, regardless of its actual qualities. Therefore, it is important that the product conveys a natural image, which is a result of its ingredients and processing, but also factors like packaging and marketing.

The importance given to naturalness by consumers is a potential challenge for novel oat products. For example, plant-based milks suffer from an artificial image, which is a barrier for consumption. However, not all consumers share this view, and those who perceive plant-based milks as natural are more likely to consume them.[16] Consumers are, to some degree, divided in how they construe plant-based alternatives, which then directly influences consumption habits. This also highlights the ambiguity of the term natural, which can have different meanings to different consumers. In general, novel food technologies are often poorly accepted by consumers and with plant-based alternatives, the production methods used are generally not well known by the general public. This might raise concern in some consumers who see such foods as highly processed and therefore unnatural and unhealthy. It is recommended for companies to be transparent about their processing methods to increase consumer trust and reduce the negative image associated with highly processed foods.

3.4 Future prospects

It can be predicted that the relative importance of sustainability aspects in food consumption will increase in the future, partly through government policy, but also because of consumer preferences. Heightened awareness on environmental issues and interest in healthy eating among consumers are important trends that affect food choice. Therefore, the demand for plant-based foods is expected to continue to rise, and this presents an opportunity for oats as well. Oats have the additional advantage of specific health functionality due to the presence of β-glucan. Although the value of health claims to consumers has been questioned, it is possible that the increasing visibility of oat-based foods on the market concomitantly sparks interest in the associated health benefits. Regardless, it is unlikely that consumers will compromise on the sensory quality of food, which highlights the need for further research on oat processing methods to improve its applicability in different food formulations. The consumer image of oats is highly positive, but more work is needed to specifically strengthen the brand of Finnish oats on the international market.

15 Roman et al. (2017)
16 Martinez-Padilla et al. (2023)

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4 OAT SIDE STREAMS

The environmental crisis and depleting natural resources in combination with the ever-growing population calls for industries to use all produced biomass to its full potential. This requires a transition to circular economy, which dictates that materials should be recycled and reused as much as possible, while minimising waste. In this way, natural resources are used as efficiently as possible. An important consideration here is the utilisation of side streams. Cereal processing generates enormous amounts of various by-products, many of which are used in low-value applications or, at worst, end up in landfills. These side streams contain valuable nutrients and other components and could be upcycled into food applications. In practice, this can mean using different processing methods to transform inedible parts of plants, such as oat hulls, into edible materials. Many side streams can also find novel uses outside of the food industry, for example as fillers in composite materials. A central concept is valorising the entire crop to conserve natural resources. However, some technological challenges remain in side stream utilisation. This chapter presents the main side streams of oat processing and some potential applications for them.

4.1 Production of side streams

The oat groat is encased in a fibrous hull – botanically, the palea and the lemma – which is generally considered unsuitable for human consumption and needs to be separated during the milling process. The hull fraction is the primary by-product of oat milling and represents approximately 20-25% of the oat grain by weight, although values as high as 36% have been reported in the literature.[1] In the industry, oat hull removal is typically achieved by an impact dehuller, followed by separation of the light hulls from the denser groats by aspiration. The milling yield (proportion of dehulled groats obtained from the starting material) is significantly affected by the success of the dehulling process, which is a balancing act: too harsh conditions lead to excessive groat breakage, while insufficient force causes incomplete dehulling. Commonly, the dehulling-separation process needs to be repeated to separate all hulls from the groats, but this also results in groat breakage and increased production of fines and thus generates more waste. It is in the interest of the miller to maximise the efficiency of the dehulling process. Therefore, cultivars with loosely attached hulls are preferred in the industry and it represents one target for oat breeders. Nevertheless, the hull fraction always constitutes a significant side stream of oat milling and its utilization deserves some attention; in Finland alone, the oats used by the food industry corresponds to approximately 40 000 tonnes of oat hulls annually. Hulless oat varieties exist, but their popularity has been suppressed by their poor agronomic performance and difficulties associated with their handling, and thus their commercial importance is low.

In addition to the milling process, by-products are also generated during the production of various oat-based foods. An important example is oat milk, which has experienced a rapid increase in popularity in the past few years and is now the most consumed plant-based milk in several countries. Oat milk is produced by slurrying oats with water and grinding the mixture to extract water-soluble components with the help of amylolytic enzymes. The liquid phase is then separated and further processed into oat milk, leaving an insoluble residue called oat pulp or oat *okara* (okara refers to the insoluble fraction obtained from soybeans during the production of tofu and soy milk). Since only a fraction of the dry matter in oats ends up in the oat milk, enormous amounts of residue are generated in the process. Oatly, one of the leading oat milk producers globally, reported production of 84 000 tonnes of residue in their factories in 2022, which highlights the need to develop suitable applications for this high-value side stream.[2]

1 Webster and Wood (2011)

2 Oatly (2023)

4.2 Current utilization of the side streams

4.2.1 Oat hulls

The hull fraction obtained from oat milling has traditionally been used as a fibre-rich addition to animal feed, although its nutritional value is low. The oat hull consists primarily of lignocellulosic insoluble fibre, with low amounts of protein and lipids (Table 1). Depending on the efficiency of the dehulling process, the industrially generated hull fraction may also contain variable amounts of starch. Poor digestibility and low nutritional value limit its use in feed. Due to the high fibre content, oat hulls are mainly fed to ruminants, although broiler chickens have also been found to benefit from a minor (3%) inclusion of oat hull in the diet.[3] Digestibility of the hull is particularly negatively affected by lignin, which binds to the cellulose and hemicellulose, rendering them largely inaccessible to enzymatic attack and microbial fermentation in the gut. Low lignin varieties are therefore preferred for feed use. The nutritional value of the hulls may be improved by alkali treatments, which help solubilise the fibre components and improve their digestibility. However, pre-treating the hulls intended for animal feed may not be economically feasible, as their feed value would be low regardless.

Table 1. Chemical composition of the oat hull. Source of the data: Schmitz (2022).

Component	% of dry weight
Cellulose	16–26
Hemicellulose	24–35
Lignin	13–25
Starch	3–16
Protein	1–7
Lipids	1–2
Ash	5–6

In addition to their use in animal feed, oat hulls are often burned for heat production, which is the most common practice in Finland. Oat hulls are a renewable source of energy and a more sustainable alternative to coal, as their combustion does not release fossilized carbon into the carbon cycle. The oat mill may have a combustion plant adjacent to the mill, allowing the hulls to be easily processed on-site, which simplifies transportation and reduces costs. The produced heat can used by the mill for its own operation, creating a circular system, or directed to district heating, for example. However, if the hulls need to be transported, overall costs may be increased to the point where economic viability is threatened. On the other hand, current government policies encourage companies to reduce their carbon footprint, which increases the viability of renewable alternatives, such as oat hulls.

Although oat milling side streams are not truly wasted when used as forage or burned, their economic value is very low. Industries are therefore increasingly looking for ways to upcycle the oat hull fraction to produce added-value products. One novel application for oat hulls is using them as raw material for xylitol production. Xylitol is a sugar alcohol which is used as a low-calorie sweetener in many food products, such as chewing gum, confectionery, and various other low-sugar foods. Oat hulls are naturally high in xylans, which can be hydrolysed to xylose and then reduced to xylitol by chemical or microbial transformation. Xylitol production from oat hulls was started on an industrial scale in Finland by Fazer in 2022, using a proprietary process. Fazer's xylitol production plant is a rare example of oat hull upcycling on an industrial scale, beyond the traditional applications in animal feed and energy production.

4.2.2 Oat milk residue

Much like oat hulls, oat milk residue is currently mostly used as animal feed or as raw material for biogas production. However, this side stream crucially differs from oat hulls in its favourable composition: oat milk residue contains approximately 30–50% protein and 15–35% dietary fibre on a dry basis. The composition is likely to be highly dependent on the exact production process, particularly regarding the amount of starch and smaller dextrins. Moisture content is high, typically about 70%. A major challenge with oat milk residue utilisation is its perishability. This has limited its recycling into food applications, despite its high nutritional value.

4.3 Prospects of the side stream utilization

Despite the recent innovations, ample possibilities remain in the development of new ways to upcycle oat side streams. Considering the sheer quantity of oat side

3 Adewole et al. (2020)

streams generated – the global annual production being in the millions of tonnes – their potential as a raw material for added-value products is still somewhat underexplored. It is beneficial from both an environmental and an economical perspective to use all produced biomass to its full extent. Moreover, as consumers are increasingly aware of environmental issues and make choices based on their values, the sustainable practice of waste stream utilization presents a marketing opportunity for businesses. Therefore, there is an incentive to develop new applications for these low-value by-products. It can be envisioned that, in the future, the currently common practice of combustion would be seen as a last resort once the biomass has been recycled into use several times, in accordance with the principles of circular economy. Plenty of research and development is still needed to utilise the side streams in an optimal way. Some potential novel uses for oat side streams are presented in this section.

4.3.1. Oat hulls

Since their digestibility and overall palatability is low, oat hulls are generally considered poorly suitable for human consumption. Nevertheless, they could be of some value as a fibrous supplement to foods. It is well known that low fibre intake is one of the biggest challenges in Western diets and contributes to a multitude of health problems. Oat hulls could be used as an addition to baked goods and other food products to increase fibre intake, especially insoluble fibre. It is also important to realise that impeded digestion of nutrients – a problem with using oat hulls in animal feed – may actually be beneficial in the human diet. However, a crucial factor is sensory acceptability, which should not be compromised due to hull inclusion. Challenges associated with adding oat hulls to foods include gritty texture, dark colour, impaired dough properties, and unpleasant flavour.

Few studies have investigated ways to process oat hulls to improve their usability in foods. In one study, an alkaline hydrogen peroxide treatment was used to partly solubilise the lignin and improve the hydration characteristics of the hull. [4] The modified hulls could be incorporated into cookies at a 20% flour substitution level while maintaining a high level of sensory acceptability. Combining an ultrasound treatment with the alkali treatment has been shown to further improve the solubilisation of oat hull fibre. In addition to fibre solubilisation, an alkaline hydrogen peroxide treatment could also be used to bleach oat hulls to obtain a more attractive light colour, which is analogous to wood pulp bleaching in paper production.[5] Oat hulls normally impart a dark colour to the food product which has a negative impact on consumer acceptance. Therefore, bleaching could be one option to facilitate incorporation of oat hulls into foods.

Another promising application for oat hulls can be found in the production of paper and composite materials. As cellulose-rich fibrous materials, cereal side streams have potential as sustainable and low-cost replacements for wood pulp. However, due to differences in composition, fibre morphology, and cell wall architecture, the pulping and papermaking qualities of non-wood materials differ from those of wood and thus research and process optimisation is required. A recent Finnish study investigated the effect of oat hull addition on the properties of paperboard.[6] Conventional softwood pulp could be replaced with 20% of oat hulls to produce paper which matched a commercial paper sample in all measured quality parameters except burst strength. As a filler in a biopolymer composite material, oat hulls were shown to have a positive impact on its mechanical properties.[7] In addition, oat hulls have been studied as a source of cellulose for the production of cellulose nanofibrils, which has a multitude of potential applications ranging from packaging and composite materials to emulsion stabilisation. Although more research is still needed, oat hulls have shown promise as a sustainable component in various technical applications. Moreover, the marketing potential of using waste streams in consumer products should not be underestimated. Considering the importance of the pulp and paper industry in Finland and the available processing expertise, oat hull upcycling presents an obvious opportunity.

4.3.2 Oat milk residue

Owing to its favourable composition, oat milk residue can be considered a potentially high-value side stream. It is clear that burning for energy production is a very

4 Galdeano and Grossmann (2006)

5 Schmitz (2022)

6 Kärkönen et al. (2022)

7 Giubilini et al. (2021)

inefficient use of this nutrient-rich resource, which contains up to 50% protein on a dry basis. The market for plant protein ingredients is expanding rapidly, and oat milk residue could be a potential source of high-quality protein to be used in plant-based dairy alternatives, snack bars, extruded products, and other high-protein foods. However, as discussed earlier, the high moisture content of oat milk residue makes it highly perishable, which complicates its processing into a safe food ingredient. The residue needs to be dried soon after production to increase its storage stability and to facilitate transportation. This is an energy-intensive process and requires specialized equipment and is therefore costly to the producer. Suitable technologies include flash drying, rotary drum drying, and microwave drying, for example. Drying of oat milk residue on an industrial scale is still uncommon, although technological solutions specially designed for this purpose do exist on the market. Careful choice of drying method is needed, as the functionality and sensory properties may be significantly altered, as suggested by studies conducted on soybean okara. The effect of various processing methods on the properties of oat milk residue requires more research.

Some alternative processing methods have been developed to avoid the need for a drying step. In a recent study, a high-pressure pasteurization treatment was applied to oat milk residue, which extended its shelf-life to at least 4 weeks when vacuum packed and refrigerated.[8] Unfortunately, the treatment also induced essentially complete denaturation of the oat proteins, compromising their technological functionality. In addition, microbial fermentation could be used to improve the safety as well as nutritional and sensory properties of oat milk residue. This has been successfully applied to soybean okara, but studies on the oat equivalent are scarce. The few existing studies show that although fermentation has potential, ensuring the microbiological safety of the final product warrants some attention.[9]

Clearly, some challenges need to be overcome to efficiently upcycle oat milk residue. It is important to note that the technological functionality of oat protein is somewhat poor, which limits its applicability in foods, and the functionality may be further reduced during processing. Recent research has shown that oat protein functionality can be improved by treatments such as mild hydrolysis or deamidation.[10] Still, it is a challenge to develop cost-effective ways to process oat milk residue into a food ingredient while preserving its functional, nutritional, and sensory properties.

8 Helstad et al. (2023)
9 Eriksson (2022)
10 Immonen (2023)

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5 CONCLUSIONS

Globally, Finland is one of the top producers of oats. The northern location and the consequent unique growing conditions provide several benefits to the Finnish oat production, for example by enabling high hectolitre weights and large groats. However, the cool and moist conditions also challenge the production chain. Over time, Finnish breeders and farmers have created ways to cope in these challenging conditions, and as a result, Finland is nowadays producing high quality oats also for export purposes.

Generally, Finland is considered a producer of high-quality oats, and Finland's food production is seen to be on a sustainable and ethical ground. These factors form a strong basis for Finland's oat export. Although Finland is already a significant oat exporter, the exported volumes are expected to further increase and to spread more towards processed oat products. Oat research, technical expertise, and innovations are within the strengths of Finland, and these enable the development and production of novel oat products in Finland. Generally, oats have positive image, and their market is expected to grow in the near future. Still, more work is needed to strengthen the brand of Finnish oats and to maintain Finland's current position as world-class oat producer in this highly competitive market.