Cereals as 'leftover biomass'

An analysis of Swedish cereal production from the perspective of feed-food competition

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Abstract

In a time with climate change and a growing population it is important to use the arable land as effectively as possible to ensure food security and minimize environmental impacts. Currently, livestock production uses 70% of all agricultural land which highlights the competition between the usage of land for crops for feed rather than for human consumption. The overarching aim of this thesis is to analyse Swedish cereal production from the perspective of feed-food competition. The objective is to understand to what extent cereals produced in Sweden can be considered a left-over biomass, that is, unsuitable for human consumption and the reasons for that. The present work looked at current use of Swedish cereals as well as the quality criteria for food and feed cereals. This study shows that most of the cereals produced in Sweden are used for feed and that a great extent of the cereals used for feed reaches food quality. However, this is not to say that all cropland that is currently used to grow cereals for feed could instead be used to grow cereals that will reach the current quality criteria. This study has shown the current quality criteria used for cereals could be lowered in some aspects for cereals that are going to be used for example food-grains and groats. The conclusion of this study is that the amount of cereals that can be considered truly a leftover biomass, from growing cereals for human consumption, is small in Sweden.

Sammanfattning

För att säkra tillgången till mat för jordens befolkning är det viktigt att använda jordbruksmarken så effektivt som möjligt. Särskilt med tanke på rådande klimatförändringar och att befolkningsmängden ökar. Idag använder animalieproduktion 70% av all jordbruksmark. Detta belyser konceptet 'feed-food competition' som beskriver användandet av jordbruksmark till att odla foder istället för att odla grödor till humanföda. Det övergripande syftet för denna masteruppsats är att analysera svensk spannmålsproduktion utifrån ett 'feed-food competition' perspektiv. Målet är att förstå i vilken utsträckning svenskt spannmål är olämpligt för humankonsumtion och orsakerna till detta. För att besvara de grundläggande frågeställningarna undersöktes användningen av svenskt spannmål samt kvalitetskriterierna för spannmål för mat och foder. Resultatet av denna studie visar att den största andelen spannmål som produceras i Sverige används till foder och att en stor del av foderspannmålet uppnår kvalitén för att användas till livsmedel. Dock är det, troligtvis, inte möjligt att odla spannmål av livsmedelskvalitet, med nuvarande kvalitetskrav, på all svensk åkermark. Den här studien visar att nuvarande kvalitetskriterier för livsmedelsspannmål kan sänkas i vissa aspekter för spannmål som kommer användas till produkter som till exempel gryn. Slutsatsen av denna studie är att endast en liten del av spannmålen som odlas i Sverige, i livsmedelssyfte, kan anses ej tjänligt som människoföda.

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1. Introduction

To achieve a sustainable food system that provides food for a growing population at the same time as reducing its climate impact is a great challenge (FAO, 2009). Today livestock accounts for 60% of the global greenhouse gas emissions from the food system and has significant negative environmental impacts (Gerber et al., 2013; Steinfeld et al., 2006). Since the 1960s meat consumption has increased dramatically on a global level (Ritchie & Roser, 2017). The expansion of livestock production has led to an increasing demand for land (Steinfeld et al., 2006). To meet the demand, forest and native grassland has been converted into agricultural land which has led to biodiversity loss and increased greenhouse gas emissions (Newbold et.al. 2016; Steinfeld et al., 2006).

The intensification of livestock production has also led to an increased feed-food competition. The concept of feed-food competition refers to the use of land for producing crops for feed rather than for crops for direct human consumption. Livestock production uses 70% of all agricultural land (pasture and arable land) and 40% of arable land is used for feed production (Mottet et al., 2017). Currently, as a global average, 3.2 kgs of human-edible feed is fed to monogastric animals to produce one kilogram of boneless meat; ruminants use 2.8 kgs of human edible feed per kilogram of boneless meat produced (Mottet et al., 2017). This means that livestock currently consume more human-edible protein than they produce. Limiting livestock production to biomass resources that humans cannot or do not want to eat - so called 'ecological leftovers' (Garnett, 2009; Röös et al., 2016) or 'low-opportunity-cost feed' (van Hal et al., 2019) - has been suggested as a strategy to cap meat production at a sustainable level (van Zanten et al., 2018). 'Low-opportunity-cost feeds' commonly include grass from non-cropable grasslands, crop residues and by-products from the food and energy industry including bran, molasses, rape seed cake, distillers grain etc. It has also been suggested that some of the feed cereals currently used are a by-product from producing cereals for human consumption, i.e., when producing cereal for bread, pasta, breakfast cereals etc. some will not reach food grade quality and therefore can be considered a biomass resource which can only be used for food production through livestock production. However, to what extent this happens is unknown.

Cereals, also called grains, are any grasses of the Poaceae family which yield starchy seeds suitable for food production (Britannica, 2020). Cereals are used for human consumption, animal feed and for industrial products. For human consumption cereals are used for a variety of food items such as bread, pasta, breakfast cereals, porridges, bars etc. Cereals are also used for malting which is later used in brewing. Livestock consumes one third of global cereal production (Mottet et al., 2017). Industrially, different compounds are extracted from cereals to produce, for example, glucose, alcohol, oils and adhesives. Cereals are also used to produce ethanol for fuel.

The overarching aim of this thesis is to analyse Swedish cereal production and use from the perspective of feed-food competition. The objective is to understand to what extent cereals produced in Sweden can be considered a left-over biomass, that is, unsuitable for human consumption and the reasons for that. This thesis also discusses the possibilities and obstacles to increased use of cereals produced in Sweden for human consumption. The cereals considered in this thesis are limited to the most common cereals in Sweden: wheat, rye, barley, and oats.

To achieve the overarching aim the following research questions were formulated:

- What is the current use of cereals produced in Sweden today?
- What quality criteria are used for cereals for different uses in Sweden and why?
- Do cereals used for feed achieve food quality? If that is the case, to what extent do cereals that are used for feed today reach the quality criteria for food?
- What are the most common reasons that cereals aimed for food fail to reach food quality?
- Could more cereals be grown for food instead of feed in Sweden?
- Finally, in order to minimize feed-food competition, to what extent can the cereals used for feed in Sweden currently be considered a leftover biomass in a typical year?

2. Background

2.1. Models for the role of livestock in future food systems

There is a debate about the role of livestock in a future food system due to the negative environmental impacts of livestock (Van Zanten et al., 2018). Van Hal et al. (2019) divides the role of animals in a future food system into three different models: 'the sustainable intensification/production pathway', 'the consumption pathway' and the 'low-opportunity-cost feedstuff/low-cost livestock pathway'. These are briefly explained here to give more background to the overall framing of this thesis.

The sustainable intensification/production pathway has its starting point in the idea that, while livestock has a necessary role in a future food system, its environmental footprint needs to be reduced by an increase in the lifetime productivity of herds and improvements in feed production methods and manure management (Breewood & Garnett, 2020). This pathway is supported by people who strongly prefer to consume animal protein and argue that it is better tasting and more nutritious than plant-based foods (Breewood & Garnett, 2020). Another argument favouring this pathway is that a food system including animal sourced food could be more resilient against ecological or economic shocks (Breewood & Garnett, 2020). For example, in the economic crisis in 2008 grain was released for human consumption, which caused an increase in feed crop prices and thereby meat prices. This led to a fall in meat consumption without, however, threatening food security because grain was still available. However, this cushioning effect on the food system can also be accomplished by freeing up grains for human consumption by decreasing the available land for food grains used for production of biofuels or alcohol during a crisis.

The consumption pathway has its starting point in that reducing or eliminating animal foods is a priority for a sustainable future food system (Van Zanten et al., 2018). This is based on the fact that it is more efficient to eat crops directly than to pass them through animals (Breewood & Garnett, 2020). The consumption pathway compares the ecological footprints of diets and, since the vegan diet has the least environmental impact, it concludes that it is the most sustainable diet (Van Zanten et al., 2018). The consumption pathway stresses that a high meat consumption, along with other factors related to the western diet, is associated with diseases such as cardio-vascular disease, obesity, and cancer (Tilman & Clark, 2014). Another argument for this pathway is that by consuming all edible crops directly, the global available food calories would increase by 70% and the protein available would double (Cassidy et al., 2013). The ecological footprint of a diet is calculated by summing the environmental impact of all food items consumed (Van Zanten et al., 2018). When calculating the ecological footprint of a diet the interlinkages in the food system is ignored. By not acknowledging food system interlinkages, human inedible by-products (for example sugar beet pulp which is currently fed to animals) would potentially not be recycled back into the food system.

The third pathway, the low-cost livestock pathway, is the least explored pathway and the only pathway taking feed-food competition into account (Van Zanten et al., 2018). This pathway includes livestock in a future food system but limits the feed to products that human cannot or do not want to eat directly, and to biomass from grassland. This means that livestock upcycle low-opportunity-cost feed such as food waste, food processing by-products and grass resources and recycle nutrient back into the food system (Van Hal et al, 2019). The low-opportunity-cost feed thereby determines the boundaries for livestock production and thereby minimizes the feed-food competition. The low-cost livestock pathway would free up a quarter of today's global arable land and compared to the vegan diet, diets containing animal protein from low-opportunitycost feed livestock use less arable land (Van Zanten et al., 2018). Since humans cannot digest all by-products from the food industry, those would become a bio-energy source or be wasted in a vegan food system. At the same time, grassland would not be used for food production. This means that additional crops would have to be cultivated to feed a vegan population which explains why the vegan diet requires more land than the low-opportunity cost feed fed livestock diet. However, a vegan diet has lower greenhouse gas emissions than the low-opportunity-cost feed-fed livestock diet since ruminants emit significant amounts of methane and manure management causes both methane and nitrous oxide emissions (Van Zanten et al., 2018).

2.2. Cereals

What all cereals have in common are that they are rich in carbohydrates and low in protein compared to legumes (Britannica, 2020) but high in protein compared to roots, fruits, and vegetables. They contain high amounts of vitamins, minerals, and fibres. For human consumption whole grain cereals are recommended due to their health benefits (Swedish Food Agency, 2019). The most common cereals in Sweden are wheat, rye, barley, and oats.

Of Sweden's 2.6 million hectares of arable land, 0.95 million hectares were on average, used for cereal production in the years 2015-2019 (Swedish Board of Agriculture, 2019). This means that cereals, on average, were grown on 37% of the arable land in Sweden in the years 2015-2019. Over the same period, 5.4 million tons of grain were harvested. On average 54% of the harvested cereals were wheat, 2% were rye, 28% were barley, 12% were oats and 4% were other cereals (Fig. 1). From 1965 to 2019, the production of winter wheat increased in Sweden whereas the production of spring barley and oats decreased (Swedish Board of Agriculture, 2020). In the same period the production of winter barley, spring wheat and rye remained more or less unaltered (Fig. 2).

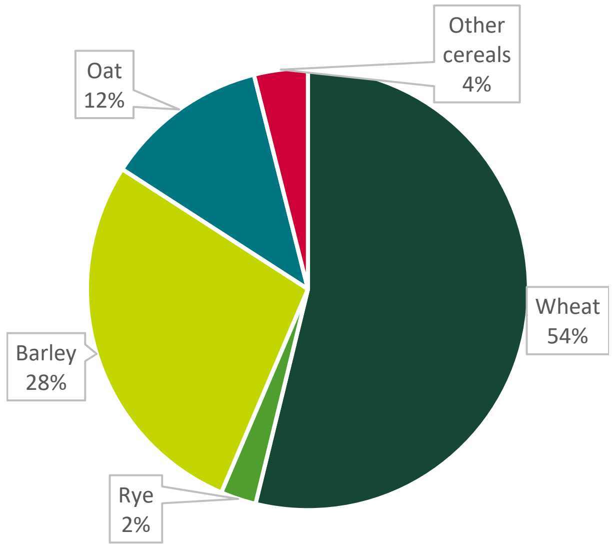

Figure 1. Average percentage of different cereals harvested each year, of total harvested cereals, in 2015-2019.

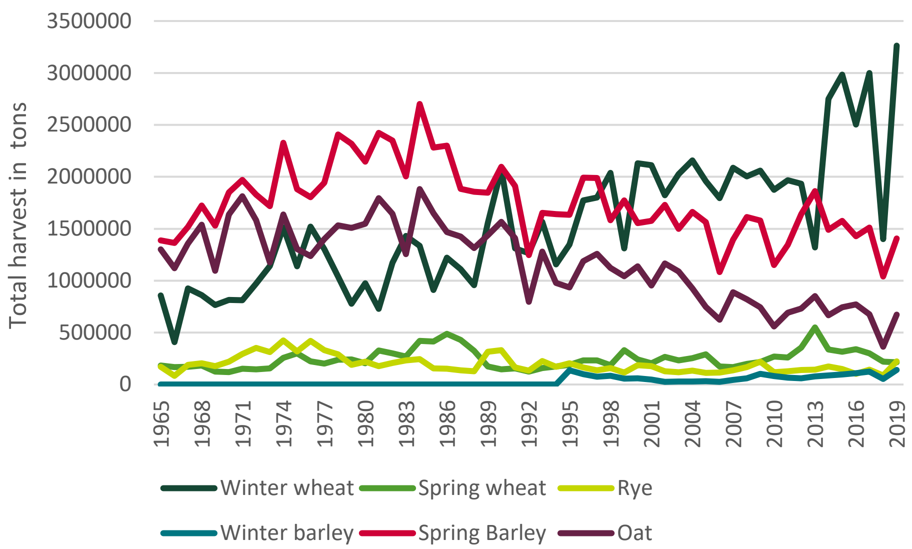

Figure 2. Total harvest of different cereals in the years 1965-2019.

Which types of cereal and cereal variety a farmer chooses to grow depends on what that cereal is going to be used for, i.e., food, feed or industry, and what conditions there are on the farm.

2.2.1. Wheat

The different kinds of wheat grown globally today are all results of the natural hybridisation of wild grasses that occurred between 7,000 and 10,000 years ago, in the fertile crescent, an area located in the middle east (Blakeney et al., 2019). They all belong to the *Triticum* group which is the most widely grown and consumed group of cultivated grasses. The most common kind of wheat currently grown is *Triticum aestivum*, also known as common wheat or bread wheat. The unique properties of wheat flour dough have led to similar wheat-based foods being developed in different food cultures around the world.

Wheat was first grown in Scandinavia in the form of single grain wheat and emmer wheat about 5,900 years ago (Swedish Board of Agriculture, 2015). Bread wheat, or common wheat, did not occur until about 1,000 years later. The first reliable data on the extent of Swedish wheat cultivation are from the 16th century. At that time wheat accounted for less than 1% of the total grain harvest in Sweden. It was not until the mid-19th century that cultivation of wheat started to grow in the country.

Wheat can be divided into two groups depending on when it is being sown: spring wheat and winter wheat (Lantmännen, 2020). In Sweden winter wheat is the most common; 2.2 million tons of winter wheat is harvested every year (41% of the total grain harvest). Spring wheat, which has a slightly higher protein content, makes up 7% of the total grain harvest. Winter wheat is more economically safe to grow than spring wheat, i.e., it is more likely to give the expected harvest, and it gives higher yields (Johansson, 2020).

Wheat can be grown under very different external conditions; it can be produced in such varied temperatures as 3 to 32 °C and with precipitation rates between 250-1750 mm (NE, 2020). A moderately stiff clay soil with a good lime content provides suitable conditions for wheat production. If the temperatures are below 3 °C there is a serious risk of frost damage and dehydration. In Sweden wheat is mostly grown on the plains in Skåne, Västergötland, Gotland, Södermanland and Uppland (Swedish Board of Agriculture, 2015).

Wheat has many health benefits if eaten in the whole-grain form (Harvars T.H Chan, 2020). Studies have shown that people who consume a higher amount of whole grains have lower risk of developing type 2 diabetes and cardiovascular diseases due to the positive effect of the dietary fibre and phytochemicals in the bran of grains (Swedish Food Agency, 2020).

Most of the wheat used for human consumption is in the form of wheat flour. Wheat that is going to be used as wheat flour is called milling wheat.

2.2.2. Rye

Rye (*Secale cereale)* originates from southwestern Asia, approximately where Turkey is located today. Earliest records are from 8,520 years ago (Britannica, 2020). It has been grown in Scandinavia since the 11th century. In the mid-19th century rye accounted for a third of all cultivated grains in Sweden (Lantmännen, 2020). At that time rye was a crucial staple food for the working class and eaten for instance as porridge and bread. At the beginning of the 20th century 60 kg of rye was eaten per person per year in Sweden; since then consumption has decreased drastically. In 1940 consumption was 26 kg per person per year and now, in the 21st century, consumption is down to 8 kg per person per year (Swedish Board of Agriculture, 2015).

Rye production mostly takes place in southern Sweden (Swedish Board of Agriculture, 2015). Winter rye, which is the predominant type of rye in Sweden, is mostly grown in Östergötland, Västergötland and northern Småland. Spring rye is mostly grown in Halland, Bohuslän, Blekinge and Småland.

Rye is often grown in climates and on soils that are not favourable for other cereals (Britannica, 2020). Winter rye is more winter-hardy than other cereals (Oelke et al., 1990). Winter rye is more productive than other cereals on sandy, infertile, or acid soils. However, preferred soils for rye are fertile, well-prepared, and well drained soils with a pH of 5.6-5.8 or higher.

Rye is the cereal containing the highest amount of dietary fibre of all the cereals grown in Scandinavia (Lantmännen, 2020). Dietary fibre is the carbohydrate that cannot be digested by the human digestive system and is important for intestinal health (Swedish Food Agency, 2019). 100 g of rye gives 70% of the daily recommended intake of dietary fibre (Lantmännen, 2020). Rye also contains essential vitamins and minerals such as B-vitamins and potassium (Britannica. 2020).

Rye is mostly used for bread, especially sourdough bread since it increases the leavening properties of the bread (Swedish Board of Agriculture, 2015). Rye is also used for crisp bread, porridge, and whiskey production (Britannica, 2020).

2.2.3. Barley

Barley (*Hordeum vulgare*) has two main varieties: six-row barley and two-row barley (Britannica, 2016). As the name indicates the varieties are distinguished by the number of rows of flowers on the flower spike. Six-row barley has a slightly higher protein content and is therefore mostly used as feed; two-row barley on the other hand is richer in sugars and is more commonly used as malt in the brewing industry. Barley can be grown both as a winter and as a spring-sown crop (Lantmännen, 2020). The most common kind of barley in Sweden is the two-row spring-sown variety.

Barley was first domesticated in the fertile crescent 10,020 years ago (Britannica, 2020). It came to Scandinavia around the same time as wheat, about 5,900 years ago, and quickly became the most produced grain in the region (Swedish Board of Agriculture, 2015). Barley was the most common cereal used for baking bread until the 17th century. At the end of the 19th century the brewing industry in Sweden started to grow. When barley breeding started the main target was to produce good malt kernels. Because of this, the barley varieties of today may completely lack the qualities that previously applied to make it suitable for flour.

Barley is adapted to a greater range of climates than any other cereal, it is more heat resistant than any other cereal and is able to grow and ripen in a shorter time (Britannica, 2020). However, barley grows best in growing seasons of at least 90 days. Barley is grown in all parts of Sweden, except for the northernmost parts (Swedish Board of Agriculture, 2020). However, it is grown further north than any other cereal. Well-drained loams and clay loams with a pH of 6.0-8.5 are most suitable for barley production (Jacobs, 2016).

Barley is rich in carbohydrates and has a moderate content of protein (Britannica, 2020). It contains beta-glucan, which contribute to lowering the body's cholesterol levels. Barley contains the same amount of beta-glucan as oats, if not more. Barley is also rich in minerals such as potassium, magnesium, and phosphorus (Lantmännen, 2020). Like other cereal products, barley is most nutritious when eaten as a whole grain. However, pearl barley, which is produced by removing the outer husk and part of the bran layer, is the most popular form of eating barley in many parts of the world (Britannica, 2020). Barley is however mainly used for producing malt in the brewing industry, especially for beer production but also for whiskey production (Swedish Board of Agriculture, 2015). A small amount of barley is used for bread and food. However, barley has great potential for new or new-old uses.

2.2.4. Oats

Oats (*Avena Sativa*) originate from southern Europe and have been grown in Scandinavia since the 18th century (Lantmännen, 2020). Oats are easy to incorporate into crop rotations and require relatively low inputs (Strychar, 2011). Oats grown for food production are preferably grown on mineral soils and a pH over 5.8 is recommended. Organogenic soils, which have a great water holding capacity, have been shown to produce lower oat yields and an increased risk of mycotoxins. Oats are sensitive to hot, dry weather and are mostly grown in cool, moist climates (Strychar, 2011). The Scandinavian climate is suitable for oat production and oats are grown in all areas in Sweden.

Oats have many health benefits, one of which is that they are rich in beta-glucans (Lantmännen, 2020). Other health benefits of oats are that they contribute to a slower glucose uptake that gives a more stable blood sugar curve and contributes with nutrients to the gut microflora. Oats are the only cereal that are naturally gluten free which is positive for people with celiac disease (Lantmännen, 2020).

Nutritionally, oats are the cereal with the highest protein content and a good source of several vitamins and minerals (Strychar, 2011). However, oats' low energy content reduces its value as feed; oats are mainly suitable as feed for horses and young calves (Strychar, 2011).

2.3. Cereal Quality

The quality standards for cereals are determined by the cereal product manufacturer in the EU and in other major markets. In other countries, government agencies provide guidelines that specify quality standards. This is the case in, for example, the United States (Delwiche, S. & Miskelly, D, 2017). However, in the United States cereal buyers may also demand specific quality attributes. All markets generally use the same indicators with different thresholds depending on the needs of the cereal food manufacturers and the type of cereal. Cereals grown for food that do not reach the quality standards are often used as feed instead (Hartman, 2020). However, cereals used as feed are often grown specifically for their purpose, and varieties with desired traits are therefore used.

Even though there are no general grading guidelines in the EU for the quality of cereals, there is an intervention system[1] with certain standards ratified by the Commission of the European Communities (EC) (Delwiche & Miskelly, 2017). The 2013 regulation states that the intervention system only applies for wheat and a producer may offer a maximum of 80 tons to the intervention agency. The

[1] The intervention system is a price support system and for grains to be taken over by the intervention agencies they must meet the EC standards. In 2013 the regulation, 1308/2013 was released. This regulation replaced four older regulations and lessened the reliance on intervention. It allowed the cereal in EU to occur more on a free market basis. Initially, the intervention system applied for wheat (with no maximum limits), corn, barley, rye, and sorghum

Minimum Requirements for Grain Traded Under Public Intervention in the European Union before the 2013 regulation is found in Appendix 1.

2.3.1. Quality system for cereals in Sweden

As in the rest of EU, in Sweden the cereal quality standards are set by the cereal product manufacturer, i.e., the bakery or other food industry (Hartman, 2020). The cereals are bought from the farmer either by a grain wholesaler such as Varaslättens Lagerhus or Lantmännen, or directly by a mill, feed company or an ethanol factory. The grain wholesaler then sells the grains to a mill, feed company or an ethanol factory. The mills process the cereals into, for example flour or de-hulled kernels, and sell these products to the end-user, for example companies in the bread industry or other cereal product manufacturers (Hartman, 2020). Each actor in the chain sets their quality standards which determine if they will accept the grain or product and at what price. However, because the cereal product manufacturers are the last actor in the chain (except for their customers) their quality standards are the point of departure for the rest of the chain. Even though each buyer in the chain sets their own quality standard the standards of different buyers do not differ much.

2.3.2. Quality parameters

The term quality means different things to different people and grain quality depends on the grain type and the end use of the cereal (Ratnavathi & Komala, 2016). Cereal quality parameters can be divided into three categories: physical (density, kernel hardness, kernel size, number of damaged kernels, moisture content etc.), safety (mycotoxin levels, foreign materials, insects etc.) and compositional factors (oil, protein, or starch content, milling yield etc.) (Jayas & Singh, 2012). Defining the quality of grains is a way of determining what end purpose the grains are suitable for.

Eurofins is one of the biggest laboratory groups in the world (Eurofins, 2020). The most commonly analyses ordered by grain wholesalers and mills that they receive are density of grains, water, and protein content, falling number (for wheat and rye), amount of deoxynivalenol, (DON) germination ability, and ocular assessment (defects on the grains such as the presence of foreign kernels, common wild oats, green kernels, broken kernels or ergot fungi) (Eurofins, 2020).

Measuring these parameters in cereals is important since they all determine the quality. The density is an indicator of overall quality (Manley et. al., 2009). Insect damage, impurities, weather conditions and moisture levels all affect the density negatively. The density also depends on the hulls of the kernels and a lower density means more hull, hence a lower milling yield (Delin, 2020). An excessive moisture content reduces the shelf life of the grain and may lead to deterioration in quality (Blakeney et al., 2009). The protein content of the grains together with the protein quality is important for the properties of the final product (Eurofins, 2020). The falling number is a measurement of the flours starch quality and enzymatic activity (Eurofins, 2020). A high falling number is preferred for wheat and rye used in the bread industry. The germination ability is especially important for barley that is going to be used as malt since germination is part of the process in converting barley into malt (Michigan State University, 2020).

An additional quality parameter for oats is colour (Winfield, Hall, and Paynter, 2007). The reason for this is that oats can get infected by a harmless fusarium species that give the oats a greyish colour (Delin, 2020). Even though the fungi infection does not result in production of any harmful mycotoxins it can give an off taste which is not desired. Another reason why colour analysis is performed is that bright flakes are desired by consumers since they give a white porridge (Winfield, Hall, and Paynter, 2007).

2.3.3. Contaminants

Mycotoxins, heavy metals, and process contaminants, such as acrylamide, are the main contaminants in cereals (Thielecke & Nugent. 2018). Mycotoxins are toxins created by moulds that grow on vegetables and other organic material (Swedish Food Agency, 2019). How many mycotoxins are produced depends on several factors in the environment such as temperature, moisture levels, available oxygen and acidity level. The mycotoxins found in cereals are Ochratoxin A, zearalenone, ergot alkaloids and trichothecenes. (Swedish Food Agency, 2019). DON is a member of the trichothecenes family and is a fusarium toxin that can occur in all cereals, especially under humid condition around harvest (Eurofins, 2020). DON is toxic to humans and animals. However, humans are more sensitive to DON than animals. Oats are more sensitive to the fusarium infection than the other cereals.

Heavy metals such as arsenic, cadmium, lead and mercury are toxic elements found naturally in the soil and taken up by cereals (Thielecke & Nugent. 2018). Chronic exposure to heavy metals can lead to a wide range of health problems.

Acrylamide is formed when the reducing sugars and the amino acid asparagine react under heated conditions (Thielecke & Nugent. 2018). Reducing sugars and asparagine are present in cereals and acrylamide can therefore occur in many fried or baked products, for example bread and breakfast cereals. Acrylamide has been classified as a potential carcinogen.

The European Union has regulations for maximum levels of contaminants in foodstuff and feed. The maximum level of different mycotoxins in different foodstuff and feed are summarized in Table 5, see appendix 2 (EC No 1881/2006) (EC No 2002/32) (EU, 2006). The maximum levels for metals and process contaminant in food is summarized in Table 6, see appendix 2 (EC No 1881/2006). The maximum amount of metals allowed in feed is summarized in Table 7, see appendix 2.

In general, higher levels of contaminants are allowed in animal feed than in food for humans (EC No 1881/2006) (EC No 2002/32) (EU, 2006).

3. Methods

3.1. Data collection on cereal use

Statistics on cereal production in Sweden were accessed through the Swedish Board of Agriculture. The statistical reports used were either published on the Swedish Board of Agriculture's website or accessed by email contact with responsible employees working at the Swedish Board of Agriculture or Statistics Sweden (SCB). There are no official statistics on the usage of Swedish cereals for different purposes and unpublished preliminary cereal balance sheets provided by the Swedish Board of Agriculture were used to make an estimate. The Swedish Board of Agriculture's statistical database was used to source information about the cereal harvest in Sweden over time.

To present more general data of the harvest and usage of Swedish cereal, averages were calculated for the years 2015 to 2019. Those years were chosen to give a present overview of the cereal harvest and usage and at the same time avoid deviations from a single year.

To get information about the main quality criteria used in Sweden, factsheets from the grain wholesalers at Lantmännen, Swedish Agro, Svenska Foder and Varaslättens Lagerhus were used. Lantmännen, Swedish Agro and Svenska Foder are the three biggest actors on the grain market. Varaslättens Lagerhus has a slightly smaller turnover but is focused on cereals.

3.2. Interviews

22 interviews were conducted over the phone or by email. The interviews were designed with open-ended questions. Hence, this part of the study was qualitative, the reason for which is to get a deeper understanding of the topic. In Appendix 3 the interviewees, their profession, where they are employed and the reason why they were interviewed can be found. All interviewees have given consent to be referenced.

Interviews about the companys' quality criteria were carried out with the grain manager or purchasing grain manager at Lantmännen, Svenska Foder and Varaslättens Lagerhus. The interviews were followed up by email when complementary questions arose. Interviewing grain managers about quality criteria was necessary since there are no official criteria with explanations in Sweden. There are also no official statistics on how much of the grains that are sold as feed is of food quality, which made it necessary to ask the companies´ grain managers to give an estimate.

Semi-structured interviews with companies from the cereal food industry, mills, and craft-baking bakeries were carried out to understand their perspective on quality, which parameters are most important for them and why. The people and the companies they are working for can be found in appendix 3. The reason for selecting those companies is that they are among the largest companies in the Swedish cereal food industry. To complement the view of larger bread companies, a number of craft bakers were also interviewed.

To understand the farmers perspectives on when to choose which crops to grow and how the growing conditions affect the final quality of the cereal, interviews with five cereal advisors at Hushållningssällskapet were carried out. The reason why cereal advisors were interviewed and not farmers is that each cereal advisor has contact with several farmers and their answers therefore are more general. Several supervisors with the title "cereal supervisor" at Hushållningssällskapet were contacted by email. The five interviews conducted were with those who replied. The interviews were either carried out over the phone or by email. The cereal advisors were also asked whether they think it would be possible to only grow cereals for food in Sweden.

4. Results

4.1. Current use of cereals produced in Sweden

In 2015-2019 Sweden, on average, had 630 thousand tons of available cereals based on the Swedish Board of Agricultures´ preliminary balance sheets from 2014/15 - 2018/19 (Swedish Board of Agriculture, 2016; 2017; 2018; 2019). On average 15% of this was used for food products, 3% for seeds, 12% for industrial products, 37% for animal/other, 9% for ending stocks and 24% was exported (Fig. 3). According to the Swedish Board of Agricultures´ cereal balance sheets from 2014/15 - 2018/19, the average of available wheat each year was 3314 thousand tonnes, the available rye was 155 thousand tonnes, the available barley 1758 tonnes, and the available oats 630 thousand tonnes (Swedish Board of Agriculture, 2020). This includes beginning stocks, production, and import.

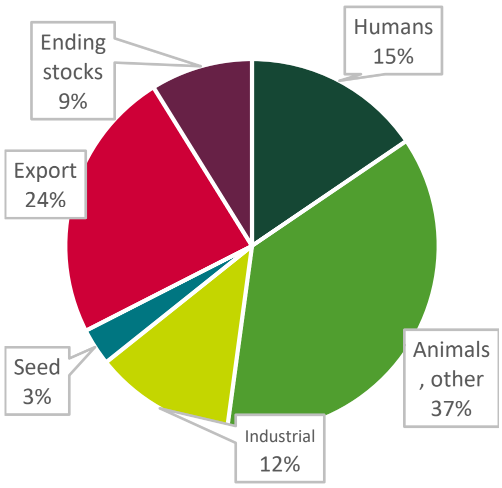

Figure 3. Average usage of cereals in Sweden 2014/15-2018/19.

In figure 4 the average usage of the four different cereals available in 2014/15-2018/19 can be seen. Of the available wheat 15% was used for human consumption, 3% for seeds, 20% for industry, 29% for animal/other, and 25% was exported (Swedish Board of Agriculture, 2020). Of the available rye, 64% was used for human consumption, 2%

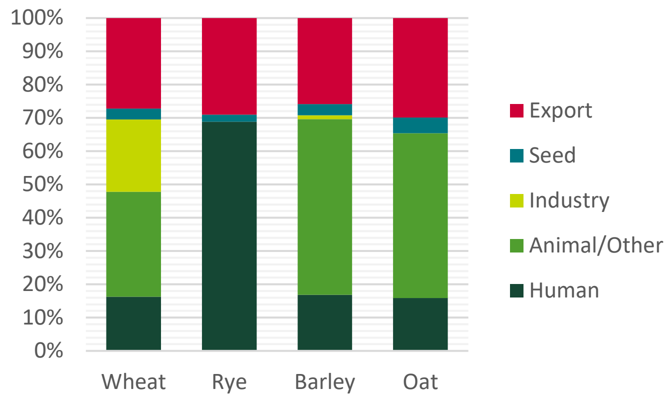

Figure 4. Average usage in percentage of wheat, rye, barley, and oats in the years 2014/15-2018/19.

for seeds, 27% was exported and 0% was used for industry and feed. Of the available barley 15% was used for human consumption (beer), 3% for seeds, 1% for industry, 47% for feed and 23% was exported. Of the available oats 17% was used for human consumption, 5% for seeds, 0% for industry, 53% for feed, and 32% was exported.

The exported wheat was sold as both food and feed equally (Gerhardsson, 2020). The exported rye, barley, and oats were mainly sold as cereals for human consumption.

4.2. Quality parameters used in Sweden

The quality standards used for food and feed grade cereals by the four major cereal companies, Lantmännen, Swedish Agro, Svenskt Foder and Varaslättens Lagerhus, are summarised in Table 1 - 4. The numbers used are for the company's basic standards for cereals purchased, some of the companies have a minimum or maximum limit on a parameter that differs from the basic standard. For example, if a value of a quality parameter is lower than the basic standard but higher than the minimum value accepted; the farmer will be paid less for the cereals than if they have reached the basic standard. However, the cereal will still be accepted for the stipulated purpose since the value is above the minimum limit. The quality standards for different cereals are explained below and further information can be found in Appendix 4.

4.2.1. Wheat

The main differences in quality criteria required for mill-wheat and feed-wheat are in: the falling number, protein content, density and the maximum amount of DON allowed (Table 2). The falling number and protein content are crucial quality parameters for flour for baking, while these parameters are not important for feed. Only Swedish Agro has thresholds for the falling number and protein content for feed wheat. The reason for having a threshold for the falling number is that they consider the falling number a good indicator of good hygienic quality (Jönsson, 2020). The reason why they have a threshold for protein, is that the animals need to get enough protein in their feed and if the cereals contain enough protein then the need for other protein sources is lower (Jönsson, 2020).

Milling-wheat has a higher requirement for density than food-wheat since this indicates a better-quality wheat for flour making (Ebel, 2020). Since spring wheat has higher protein levels than winter wheat some of the companies have a higher protein requirement for milling spring wheat than for milling winter wheat.

Table 1. Quality criteria for mill and feed wheat used in Sweden.

	Wheat	
Quality parameter:	*Mill*	*Feed*
Falling no (s)	220[1]/250[2,3,4]	230[3]
Water content (maximum, %)	14[1,4]/14.5[2]/14-23[3]	14[1,3]/15[2]/14-23[3]
Protein content (minimum, %)	Spring wheat: 13[1,4]/*13[3] Winter wheat: 11,5[1,4]/11.1-11.5[3] Spring and winter wheat: 11-11.5[2]	Spring and winter wheat: 11.1-11.5[3]
Density (g/l)	775[1]/780[2,3,4]	740[2,4]/730[3]
Content of foreign grains (maximum, %)	2[1,2,3,4]	5[2]/2[3,4]
Content of green kernels (maximum, %)	0.5[1]/5[2]/0[3,4]	5[2]/0[3]
Content of burned or discoloured kernels (maximum, %)	0.5[1]/3[2]/0[3,4]	5[2]/0[4]
Content of smashed or animal eaten kernels (maximum, %)	3[1,4]/5[2]/0[3]	5[2]/0[3]/3[4]
DON (maximum amount of ug/kg)	1250[1,2,3]	8000[3]

[1] Varaslättens Lagerhus
[2] Lantmännen
[3] Swedish Agro
[4] Svenska Foder

If no data is entered, it means that no numbers exist

When baking bread with wheat flour industrially it is important to have a strong protein network since this makes the dough less likely to tear apart in the baking process (Hansson, Jandergren & Larsson, 2020). Today the bread industry requires flour of at least 11% protein. Having a higher protein level represents a security factor for the bread industry.

Since the quality of wheat flour is influenced by various attributes it is not only the protein level that is important for bread manufacturing companies (Poulsen, 2020). The different attributes of a flour affect each other and this correlates with the baking quality of the flour. However, the interplay between the attributes is not completely known. To find flour with good baking quality is mostly done by test baking.

Bread manufacturing companies buying flour from Lantmännen's mill, which is the largest mill in Sweden, are interested in the flours' falling number, gluten quality and the starch properties (Poulsen, 2020). The gluten quality in flour determines the bread's ability to rise, which is not only important for the desired structure but also for the bread to keep fresh (Karlsson, 2020). Gluten is not measured as a quality parameter by the grain wholesalers. However, since gluten is a complex wheat protein, the total protein levels in the wheat flour can give an indication of the gluten levels. To investigate the gluten quality, the starch can be washed out of the dough and the gluten that is left can be investigated. This is done, for example, by the Saltå Kvarn company (Friberg, 2020). A certain level of ash content may also be required by the bread industry (Lööf, 2020; Poulsen, 2020). The ash content is a measure of the mineral content in the flour (Ramlösa Kvarn, 2020).

One of the most important quality factors for the bread industry is that the flour must be of an even quality (Karlsson, 2020) (Lööf, 2020). In craft bakeries there is a greater possibility to bake bread of flours of different protein levels etc. since the baking is done on a smaller scale and the baker can be more flexible in adjusting to the flour (Hansson, Jandergren & Larsson, 2020). However, a good falling number is essential also for craft bakers to get the dough to rise properly (Boudet, 2020). The protein content is not as important, and it is possible to bake bread with flour of only 6.5% protein. To bake bread using lower quality flour requires specific skills on the part of the baker (Hård, 2020).

When making pasta the quality demands of the flour is more or less the same as the ones for flour for bread (Poulsen, 2020). Pasta is mainly made with durum wheat since durum wheat has a high level of protein and a gluten content with a good balance of glutenin and gliadin, which gives the desired traits for pasta dough (De Cindio & Baldino, 2016). However, pasta could be produced using other kinds of wheat. The reason why the falling number is important in pasta making is that it is a measure of the enzymatic activity which affects the water uptake.

When making biscuits it is important that the flour have a low amount of protein and a low water holding capacity since biscuits are not supposed to rise (Hansson, Jandergren & Larsson, 2020; Poulsen, 2020). Lantmännens mill has a requirement of maximum 11% protein in their biscuit flour (Poulsen, 2020). The same is valid for breakfast cereals (Poulsen, 2020). For biscuits it is also important to have flour with gluten with the desired traits since you do not want the dough to contract to much (Friberg, 2020).

The wheat berry is the whole wheat kernel except the husk, and it can be eaten as an alternative to rice or pasta. The only important quality parameters when producing wheat berries are that the grains must be hygienic and sound. Saltå Kvarn is a company producing wheat berries. Even if their grain purchaser Peter Friberg states that protein level and falling number are not important for wheat used to make wheat berries, they still have requirements on protein and falling numbers for all the wheat that they buy (Friberg, 2020). The reason for this is that it would be hard logistically for the company to separate the wheat they purchase for wheat berries from the wheat they purchase for other products. This is mainly due to the fact that the company has a limit number of silos. The same is valid for rye consumed as a whole kernel.

4.2.2. Rye

The quality criteria used for rye by the four cereal wholesalers is found in Table 2.

Table 2. Quality criteria for food and feed rye used in Sweden.

Quality parameter:	**Rye**	
	Food	*Feed*
Falling no (s)	120[1]/150[2,3,4]	
Water content (maximum, %)	14[1,4]/14.'5[2]/14-23[3]	
Protein content (minimum, %)		
Density (g/l)	720[1,3]/750[2]/740[4]	
Content of foreign grains (maximum, %)	2[1,2,3,4]	5[2]
Content of green kernels (maximum, %)	0.5[1]/5[2]/0[3,4]	5[2]
Content of burned or discoloured kernels (maximum, %)	0.5[1]/3[2]/0[3,4]	
Content of smashed or animal eaten kernels (maximum, %)	0,5[1]/5[2]/0[3]/3[4]	
DON (maximum amount of ug/kg)	1250[1,2,3]	

[1] Varaslättens Lagerhus *If no data is entered, it means that no numbers exist*
[2] Lantmännen
[3] Swedish Agro
[4] Svenska Foder
**Spring Wheat, **Winter wheat*

The rye that does not reach the quality criteria for food gets downgraded to feed rye (Ebel, 2020). Rye for food does not have a required protein content since it is mainly used for crispbread and therefore does not need to have rising properties in the flour (Gerhardsson, 2020).

The falling number and adhesive properties are essential for the baking quality of rye (Poulsen, 2020). The adhesive properties depend on both the starch and the pentosanes ability to take up water. If the dough is not adhesive enough it will fall apart and be impossible to bake. If the falling number is too low the dough will be too sticky and it will be hard to shape the dough. Since rye does not contain as much gluten as wheat the falling number and adhesive properties are crucial for the structure of a rye dough. The structure of the dough is important both when baking hard bread and soft rye bread.

The rye grain can be boiled and eaten as an alternative to rice in the same way as wheat berry. As with wheat berries, the only important quality criteria for the rye grain, eaten as a whole kernel, is that the grain must be hygienic and sound (Friberg, 2020). The falling number, protein level or density does not matter since the kernel is not milled. Sometimes the rye kernel is dehulled in the process of making rye grains as an alternative for rice. The reason for this is that it gives a more pleasant structure to the 'rye-rice' and when producing 'rye-rice' an important quality parameter is therefore that the kernels must be easy to dehull (Friberg, 2020). Rye flakes can be used to make porridge and the only important quality parameters are that the grain must be hygienic and sound.

4.2.3. Barley

The main difference in the quality requirements for barley for malt and for feed is the protein content (Table 5). There are no requirements for protein content in barley for feed and the density requirement is only slightly lower for feed barley than for malt barley. Compared to other grains malt barley has a requirement of a maximum and a minimum protein content. The required protein is within a certain range around 10%. The interval required differs slightly between the four different companies. The four companies do not have any quality criteria for barley aimed for human consumption other than malt.

Table 3. Quality criteria for malt and feed barley used in Sweden.

+ **Quality parameter:**	**Barley**	
	Malt	*Feed*
Falling no (s)		
Water content (maximum, %)	14[1,4]/14.5[2]/14-23[3]	14[1,3]/15[2]/14-23[3]
Protein content (minimum, %)	10-11.5[1,4]/10-11[2]/9.6-11[3]/	
Density (g/l)	640[1]/650[3]/620[4]	630[2]/650[3]/670[4]
Content of foreign grains (maximum, %)	2[1,2,3,4]	5[2]/2[3,4]
Content of green kernels (maximum, %)	0.5[1]/5[2]/0[3,4]	5[2]/0[3,4]
Content of burned or discoloured kernels (maximum, %)	0.5[1]/0[2],[3,4]	1[2]/0[3,4]
Content of smashed or animal eaten kernels (maximum, %)	3[1]/5[2]/0[3]/2[4]	5[2]/0[3]/3[4]
DON (maximum amount of ug/kg)	1250[1,2,3]	8000[3]

If no data is entered, it means that no numbers exist

[1] Varaslättens Lagerhus
[2] Lantmännen
[3] Swedish Agro
[4] Svenska Foder

The barley varieties grown in Sweden are quite tough which affects the gluten network negatively when baking bread industrially (Karlsson, 2020). The reason for this is that barley has a thick bran and even when barley is ground finely, there will be sharper particles left. The varieties also have a bitter taste which is not desired. Therefore only 10-20% of barley flour is used in bread baking. Barley can be eaten as a whole kernel without the hull and as flakes. When producing those products, the important quality parameter is that the grains should be hygienic, sound, and easy to dehull.

4.2.4. Oats

Oats do not have protein requirements for either food or feed oats (Table 6). The main difference in quality requirements for food and feed oats are density and the maximum allowed DON content. The density requirements for feed oats are slightly higher for food oats than for feed oats. Lantmännen does not have any requirements for density since density is controlled indirectly by sorting over sieves (Gerhardsson, 2020). The reasons why all companies have a higher maximum level of DON allowed in oats than for the other cereals are that oats are more sensitive to fusarium infection than other grains (Ebel, 2020). If the same limit value as in other cereals were applied to oats, the opportunity to grow oats in

Sweden, among other places, would be severely limited (Livsmedelsverket, 2020). Since oats have many nutritional benefits in the diet the limit for DON is set a bit higher in oats as a compromise between the cultivation realities and the health aspect. Compared to, for example, wheat, oats are also consumed less.

Oats for food have a maximum level of grey kernels of around 2% and oats for feed have a maximum level of grey kernels of around 4% (Lantmännen, 2020) (Swedish Agro, 2020) (Varaslättens Lagerhus, 2020).

Table 4. Quality criteria for food and feed oats used in Sweden.

	Oats	
Quality parameter:	*Food*	*Feed*
Falling no (s)		
Water content (maximum, %)	14[1,4]/14,5[2]/14-23[3]	14[1,3]/15[2]/14-23[3]
Protein content (minimum, %)		
Density (g/l)	540[1]/560[3,4]	540[1]/550[2]/500[3]/520[4]
Content of foreign grains (maximum, %)	2[1,2,3,4]	5[2] /2[1,3,4]
Content of green kernels (maximum, %)	0,5[1]/0[2,3,4]	0,5[1]/0[2,3,4]
Content of burned or discoloured kernels (maximum, %)	0,5[1]/0[2,3,4]	0,5[1]/0[3,4]
Content of smashed or animal eaten kernels (maximum, %)	3[1]/5[2]/0[3]/2[4]	3[1]/0[3]/3[4]
DON (maximum amount of ug/kg)	1750[1,2,3,4]	8000[1,2,3,4]

[1] Varaslättens Lagerhus

[2]Lantmännen

[3]SwedishAgro

[4] Svenska Foder

If no data is entered, it means that no numbers exist

For Lantmännen's mills customers (which are companies in the food industry manufacturing cereal products) the colour of the oats and that the grain should be easy to dehull are important (Poulsen, 2020). If the grains are hard to dehull the yield of the oats will be lower.

For the oat-drink company Oatly the quality demands on oats are the EU's regulation on microorganisms, a maximum content of foreign grains of 0.5%, maximum 0.1% burned kernels, and a maximum water content of 12% (Oatly, 2020). The reasons why the water content is set to 12% is to minimize the risk of contamination during storage. The company does not have any requirements about protein, but it is normally around 14%.

Oat grains can, like other cereals, be boiled and eaten as an alternative to rice. When producing oats for this purpose the quality parameters of importance are that the oats should be hygienic sound and easy to dehull (Friberg, 2020).

4.2.5. Quality of Swedish cereals produced today

Farmers can choose to produce cereals destined either for food or feed (more on how this decision is taken in Section 4.3). There are no statistics on the number of cereals destined for food that reach food standards, but Gottfridsson and Pålsson both make an assessment the cereal crops of most farmers who choose to grow cereal varieties for food do in fact reach the quality criteria for food grains (Gottfridsson, 2020; Pålsson, 2020). If the cereal is grown to be sold as food grains and does not reach the quality criteria the most common reasons are weather conditions, fungi, pests, and diseases (Hultman & Strand, 2020; Pålsson, 2020). The greatest challenges when it comes to reaching the quality criteria are to get a high enough protein level and a high enough falling number for wheat and rye (Gottfridsson, 2020).

The amount of protein in the cereals depends to a large extent on nitrogen fertilization. To reach the amount of protein required in, for example, bread wheat, fertilization must be performed at the right time and with precision It is also important that enough fertilizer be used (Hultman & Strand, 2020). Since organic fertilisers are used in organic production it is more difficult to pinpoint the right time for fertilization as organic fertilisers usually contain less plant-available nitrogen. This is because it is harder to know when the nitrogen will be available to the plant but also because it can be difficult to use machinery for applying organic fertilisers in the growing crops without damaging them. Getting the right amount of protein in barley for malt is harder than for other grains since the quality criteria require the amount of protein to be within a certain range (Gottfridsson, 2020). For the other cereals there is just a minimum limit of protein required.

The falling number depends on when the cereal is harvested (Gottfridsson, 2020). It is important to harvest at the right time before the kernel has started to germinate. Wheat for example, is ready for harvest at the end of August or in early September. If there isn´t time to harvest the yield before rainfall comes, there is a big risk that the kernels start to germinate. Different varieties of wheat have differing sensitivities to this.

According to Gerhardsson, 80% of the wheat grains used as feed or for ethanol production, normally meet the quality criteria limits to be used as food (Gerhardsson, 2020). The reason for this is that Sweden only produces 20% of the demand for animal feed wheat. To meet the demand for animal feed, milling wheat is therefore used as animal feed. Approximately 15-20% of the barley used for feed might reach malt barley quality (Gerhardsson, 2020). Rye or oats that are used for feed generally do not reach food quality. However, the amount of cereal reaching food quality varies from year to year depending on the weather.

In the 2020 season, 75% of the cereals that were sold as feed grain from Varaslättens Lagerhus was of sufficient quality to be sold as food grain; in 2019 it was around 60% and normally the proportion of cereals sold as feed grain that is of sufficient quality to be sold as food grain is around 50-60% (Delin, 2020). There are several reasons for which a higher amount than normal of cereals of food grain quality were sold as feed grain in 2020 (Delin, 2020). For example, the demand for feed grains in the EU has been greater this year than normal because Great Britain, which normally produces a large amount of feed grain, has had a poor wheat harvest. At the same time Spain, which normally imports a lot of bread wheat, has had a better harvest than normal and has therefore not imported any bread wheat.

In 2019 and 2020 almost all cereals that Svenska Foder bought reached food quality (Ebel, 2020). Even wheat varieties destined for feed were of good enough quality to be used for food.

Some years there is a lack of enough cereals reaching food quality in Sweden (Delin, 2020). However, this is unusual. The last time it happened to a significant extent in Sweden was in 2011 and 2012 when significant proportions of oats had too high levels of DON. The harvest in 2018 was considerably smaller than normal due to the drought. However, there was no lack of cereals reaching food quality (Gerhardsson, 2020). In those years that cereal yields are lower than normal it is primarily feed grains that are imported.

4.3. Influencing factors on which crops farmers choose to grow

As mentioned earlier farmers choose to grow cereals for food, feed or industry. Different varieties of a cereal possess different attributes that are suitable for the end-purpose of the grain. However, the farming conditions and practices also determine the quality of grains.

There are several factors that influence which crops and varieties the farmer chooses to grow. Some of the factors are demand, location (climate, soil condition, pH of soil etc.), field size, crop rotation, technical factors (such as machines available, storage space etc.), logistics at harvest (avoiding all crops being ready to be harvested at the same time), tradition, profitability, and security (Hultman & Strand, 2020; Gottfridsson, 2020). Farmers that have organic production are more dependent on good crop rotation than conventional farmers (Hultman & Strand, 2020). Which buyers are available in the nearby area is also an important factor since transportation is expensive (Pålsson, 2020). For example, Norrköping has the biggest ethanol factory in Sweden and therefor it is common for farmers in the area to grow cereals for ethanol.

Different cereal varieties have been bred for different purposes and for different growing conditions. For example, winter wheat can be suitable to grow for food, as a raw material for industry or for feed (Scandinavian Seed, 2020). However, different varieties are chosen depending on what the wheat is intended for. When growing winter wheat for bread a high protein content and good baking properties are desired; when it is to be used as a raw material in industry a high starch content is important and when the aim is feed both a high protein and starch content is desired. An example of two winter wheat varieties with different properties are "Ellvis" and "Torp" (Scandinavian Seed, 2020). "Ellvis" has great baking properties since the falling number is high whereas the winter wheat "Torp" is more suitable for feed or ethanol production since it has a rich starch content. Another factor influencing which variety is chosen is how the variety performs in a particular climate. Some varieties are more winter hardy than others and different varieties have different lengths of growing season. For example, varieties with a shorter growing season are preferred in northern Sweden since the growing season there is shorter than in southern parts of the country (Johnson, 2020).

Cereal varieties suitable for feed provide greater yields than varieties suitable for food (Gottfridsson, 2020). Varieties grown for food require more effort and inputs, which means that farmers must invest more to grow these varieties. There are some varieties that provide high yields and can reach the quality necessary for food cereal (Gottfridsson, 2020). However, there is no guarantee that those varieties will reach food quality.

Another aspect that influences the farmers' choice of grain is that prices fluctuate; some years there is an additional payment for cereals for food but other years there is not (Gottfridsson, 2020; Pålsson, 2020). Whether there is an additional payment or not is influenced by the world market. To secure income some farmers choose to sell their yield before harvest (Gottfridsson, 2020). If they are not able to fulfil the quality criteria at harvest, they must pay a penalty fee; if they get a harvest of better quality than expected there is no extra bonus. This makes growing cereals for feed more economically secure than growing cereals for food.

The price difference between cereals for feed and food also influences the farmer's choice (Hultman & Strand, 2020; Pålsson, 2020; Gottfridsson, 2020). As it is today farmers get paid slightly more for food cereals than for feed cereals (Pålsson, 2020). However, since it takes more effort and inputs to produce food grains the profitability difference is relatively small.

4.3.1. The conditions for arable land in Sweden to grow cereal of food quality

To investigate the possibility of growing cereals for food where cereals are currently grown for feed, it is essential to understand the extent to which cereals produced in Sweden could be considered an unavoidable leftover biomass unsuitable for human consumption. Four cereal advisors were asked if they think, from a crop growing perspective, whether it would be possible to grow only cereals of food quality in Sweden. Three out of the four said that they do not think it would be possible (Pålsson, 2020; Lindell, 2020; Gottfridsson, 2020; Strand, 2020). This assumption is based on the fact that cereals must fulfil the current quality requirements from the food industry. However, the quality criteria used today are higher than necessary for some cereal food products.

The reasons why the cereal advisors do not think that it would be possible are that the climate in certain areas is not favourable, or that the soil is not fertile enough, or a combination of the two (Gottfridsson, 2020). For example, it can be difficult to grow cereal with high enough protein levels on a sandy soil in an area with low precipitation since sandy soils have low water holding capacity. Another example is that some soils might have high levels of heavy metals and cereals grown on those soils therefore can exceed the allowed heavy metal content for human consumption (Strand, 2020). Cadmium (Cd) is a metal that can rather easily be taken up by crops, but the uptake depends on various factors (Eriksson, 2009). Wheat is the cereal that, generally, is most prone to taking up cadmium whereas barley and rye is not as prone, oats are somewhat prone to take up Cd compared to wheat. An example of an area with a high amount of cadmium in arable soils is Österlen in Skåne. Soils can also be infected by fungi which makes it difficult to produce cereals hygienic enough for food. Since there are lower requirements of protein in cereals for feed and that higher amounts of heavy metals and mycotoxins are permitted the cereals grown on soils mentioned above might be able to be used for feed but not food.

To determine the exact extent to which food grade cereals could be grown instead of feed cereals in Sweden would require a deeper analysis than is possible in this thesis. To be able to do so it would be necessary to map the country's soil and climate conditions together with exact climate requirements to reach food quality. The ability for different varieties of food cereals to grow in different areas would also need to be investigated. In northern Sweden it can be hard to grow cereals of bread quality since the harvest takes place later in the autumn which affects the falling number negatively (Gottfridsson, 2020) However, some varieties with a shorter growing period and with the desired attributes might succeed in reaching food quality (Johnsson, 2020).

Another aspect is that even though a certain cereal variety could reach food quality in any specific area it is not beneficial for the soil to grow the same crop every year (Lindell, 2020). It can be difficult to find different cereal varieties than can grow in any specific area and reach food quality. For example, it is hard to grow oats for food on a sandy soil and barley for malt on an organic soil rich in humus. However, because the quality, to a large extent, depends on the weather conditions it could be possible to reach food quality for most cereals some years (Pålsson, 2020) (Hultman, 2020).

4.4. Cereals as leftover biomass

Finally, in order to minimize feed-food competition the question needs to be answered of what proportion of cereals is produced in Sweden that can be considered leftover biomass and thereby unsuitable for human consumption. As previously stated, a great proportion of the cereals used as feed in Sweden is of food quality (Gerhardsson, 2020; Delin, 2020; Ebel, 2020) and if a farmer aims to achieve food quality this is often achieved (Gottfridsson, 2020; Pålsson, 2020). If food quality is aimed for but not achieved it is mostly due to weather conditions, fungi, pests, and diseases (Hultman & Strand, 2020; Pålsson, 2020).

The most common quality parameters that fail to be satisfied are the protein level and falling number for rye and wheat. The cereals that fail to reach the current quality criteria for food can be considered left-over biomass, but they do not necessarily need to be. If cereals do not reach a high enough protein or falling number, they might not be suitable for flour but can still be used for other food products such as food grains (ex. wheat berry). In summary, the quantity of cereals that can be considered truly a leftover biomass from growing cereals for human consumption is small.

However, this is not to say that all the cropland currently used to grow cereals for feed on could instead be used to grow cereals that would reach the current quality criteria. Some of the arable land in Sweden might not be suitable for production of high-quality food cereals but exactly how much is not known. One reason for this unsuitability is that some of the arable land contains amounts of heavy metals high enough to possibly lead to elevated concentrations in the cereals (Strand, 2020). As earlier mentioned, an example of this is that cereals grown on soils with high levels of cadmium (Cd) can contain a higher content of Cd than allowed in food cereals (Eriksson, 2009). However, a higher amount of Cd in the soils does not mean that the cereals must contain an excessive amount of Cd and vice versa. The amount of Cd taken up by a cereal depends on several factors and is difficult to predict. Since a higher percentage of heavy metals is allowed in feed than in food those soils could be suitable for growing cereals for feed but not cereals for food. However, it might be possible to grow cereals, or other food crops, that are less prone to taking up cadmium on arable land with a high concentration of cadmium in the soil. An example of a crop that is not as prone to taking up cadmium, as wheat, is barley (Eriksson, 2009). As stated earlier, a deeper analysis than possible in this thesis would be required to determine the exact extent of food grade cereals that could be grown instead of feed cereals in Sweden. However, these croplands could also be used for other purposes.

5. Discussion

5.1. Usage of cereals in Sweden

As the results state the largest percentage of Swedish cereals is used for "animals/other" (37%), which is more than double the percentage going for human consumption (15%). However, the statistics used are the Swedish Board of Agricultures' estimated cereal balance sheets which are not official statistics. The values are estimates, which creates uncertainty in the results. Furthermore, it is not known exactly what those cereals which are exported are used for. There are no official statistics on what the cereals produced in Sweden are used for. If this were to be documented by, for example, the Swedish Board of Agriculture, it would give a better picture of how effectively Sweden is using its arable land.

In the Swedish Board of Agriculture's estimated cereal balance sheets which are used to calculate the average use of Swedish cereal there is a category for feed called "animal/other". The "other" in this category refers to the cereals that are left for storage on farms (Eklöf, 2020). It is not known what the cereal left for storage on farms is used for as it can have several different purposes including feed. It can therefore not be assumed that the whole "animal/other category" is used as feed.

5.2. Complications of defining quality

In the results it can be seen that the quality criteria limits for feed are slightly lower than food. The main reason for this is that cereals for food are refined for different food products and are therefore more susceptible to defects. This can lead to the assumption that feed grains are of lower quality than food grains which is not the case. This is a question of defining quality. According to Oxford dictionary quality is defined as *"The standard of something when it is compared to other things like it; how good or bad something is"* (Oxford Advanced Learner's Dictionary, 2020). Comparing cereals grown for different purposes from a quality perspective is therefore not possible. Different varieties of cereals are used, and different qualities are needed when producing for feed as opposed to when producing for food. The cereals' attributes affect the animals eating them and it is therefore important that they have a good nutrition and hygiene profile. However, cereals that are destined for food, but which do not reach, or exceed, the quality criteria limits can be used as feed instead. This can be seen in, for example, Lantmännens' quality criteria sheet, where cereals not reaching the quality limits for food can be downgraded to feed or raw material for industry. However, this does not mean that cereals for food and feed can be compared from a quality perspective; this is only possible for cereals destined for the same purpose.

To define what quality means for cereals destined for food can also be problematic. As it is today, the quality parameters used are customized for the needs of industrialized food production. For the bread industry it is important to have an even quality of flour with high enough protein levels and good baking properties. The competitiveness with other brands is also important for companies producing, for example, bread to a large extent (Hansson, Jandergren & Larsson, 2020). If the quality attributes of flour vary, it is hard to produce large amounts of bread of an even quality, However, the craft bakers Boudet and Hård (2020) both state that the origin and production method, so called extrinsic quality parameters (Espejel, Fandos Herrera & Flavian, 2007) of the cereals are the most important quality factors for them. In craft bakeries there is a greater possibility to bake bread of flours of different protein levels etc. since the baking is done on a smaller scale and the baker can be more flexible in adjusting the baking to the flour (Hansson, Jandergren & Larsson, 2020).

Another aspect of this is that the quality parameters used are mainly customized for the cereal products that are produced to the greatest extends, bread. If the quality criteria were set more according to the needs of individual food products, some of the food parameters required could be lower. For example, cereals that are going to be used as flakes or food grains (for example wheat berries) do not need to reach a certain level of protein or falling number. As stated in the results the main quality aspects that are important when it comes to production of those particular products are that the cereals be hygienic, sound, and easy to dehull.

5.3. Quality of Swedish Cereals

A common argument why most cereals produced are used for feed is that the arable land in Sweden does not have the prerequisites to grow anything other than crops for feed. However, the results show that around 50-60% of the cereals sold as feed by Varaslättens Lagerhus and about 80% of the wheat grains sold by Lantmännen possess the necessary quality to be sold as food. This shows that a big proportion of the cereals used for feed could be used for human consumption instead. The cereals that are sold as feed which do not reach food quality are most probably varieties aimed for feed and the farmers growing them have therefore had no intention of achieving food quality. The percentage of how much of the cereals that are sold as feed and do, in fact, reach food quality are estimates made by grain managers. That they are only estimates creates uncertainty in the results. To be able to know how much of the cereals produced in Sweden that could be used for human consumption, the cereals' quality attributes should be documented. The documentation would make it possible to see what possibilities there are to direct the consumption of cereals to direct human consumption.

5.4. Conditions for growing cereal of food quality on Swedish arable land

It is not known how large the proportion of the arable land in Sweden that has the potential to produce cereal of food quality. As discussed earlier, to investigate this it is crucial to know what food quality is being considered. Maybe it is not possible to produce mill wheat with a high protein content everywhere. However, it might be possible to produce cereals that could be used for other kinds of food. The common opinion among the cereal advisors interviewed, which is stated in the result, is that it would probably not be possible to grow only cereals of food quality in Sweden due to the conditions of the arable land. This opinion is, however, based on the current quality criteria used.

However, if different cereals varieties than the ones used today were grown it might be possible to grow food cereals in regions where cereals for feed are currently produced. An example of this is Västerbottens län, where the cereals harvested are almost only for feed. A new project with the aim of growing more cereals for bread in the county showed that the Finish wheat varieties Helmi and Anniina grow well in the area (Johnsson, 2020). These wheat varieties have good baking properties, a shorter growing season, and a higher yield than the Swedish wheat variety with the shortest growing season. Since the growing season in northern Sweden is shorter than in the south of Sweden this shows that the Finnish varieties suit the climate in northern Sweden better and that it is possible to grow wheat for bread in the northern parts of Sweden. This is just one example of where cereals for food could be grown but where cereals for feed are grown instead. Hypothetically, there could be more regions in Sweden where the situation is the same.

Another example of varieties that are suitable for human consumption, but which are not used today are older barley varieties. As stated in the background, barley was the most common cereal used for baking bread until the 17th century, when barley breeding started with the aim was of producing good malt kernels. This resulted in the barley varieties used today lacking the necessary attributes to be used for flour or groats. If older varieties of barley could be used again, they would probably be more suitable for flour and groats. Since those varieties were grown in Scandinavia in the 17th century, they are probably also appropriate for the Scandinavian climate

To be able to know to what extent it would be possible to grow cereals for food, from a farming perspective, more research on the topic is needed. To answer the question, it is also important to re-evaluate what quality criteria are necessary to use cereals for food. This research would facilitate decisions on what steps to take for a future sustainable food system.

5.5. Increasing the percentage of cereals used for human consumption

Having a larger price difference between grains for food and feed would increase the motivation for farmers to grow cereals for food as well as offering greater economic security for the farmer (Gottfridsson, 2020). However, this might lead to an increased import of cheaper cereal food products. Furthermore, this is a complex economic question which needs to be analysed deeper than possible in this thesis. Another aspect is that if fewer farmers kept animals the production of feed would be lower which would free up land to, for example, grow cereals for direct human consumption or to grow other crops for human consumption such as pulses, legumes or vegetables (Gottfridsson, 2020). The land that would be freed up could also be rewilded which increases biodiversity. This does not mean that the livestock production in Sweden needs to be erased. If the production shifted towards the 'livestock on leftover' model, as mentioned in the background, there would still be animals kept but to a lesser extent than today, especially in terms of pigs and poultry (Röös et.al., 2016). Another aspect of the effective use of land is whether arable land should be used for other purposes than food or necessary raw material for the industry. For example, growing barley for malt is not necessary from a health perspective. In a future with weaker food security, we might need to rethink what it is that is ethically defensible to use arable land for.

At the present time, Sweden is self-sufficient in cereals and the demand for cereals for food is met (LRF, 2020). In view of the competition between feed and food we need to move in the direction of increasing the proportion of cereals going to direct human consumption. According to The Swedish Food Agency's´ latest report on food and nutritional intake among adults in Sweden, *Riksmaten 2010-11*, Swedish adults on average get 47% of their energy intake from carbohydrates (including carbohydrates from alcohol) and 32% of the carbohydrates consumed comes from cereals (Amcoff et al. 2012). The latest Nordic Nutrition Recommendations from 2012 recommends that 45-60% of the energy intake should come from carbohydrates (Nordic Council of Ministers, 2014) which means that there is, from a nutritional point of view, space to increase the consumption of cereals. In addition to this only one out of ten Swedish adults consume the recommended amount of wholegrains (Livsmedelsföretagen, 2020). When producing whole grain products, the entire cereal grain is used which minimizes wastage and as stated in the background, a high whole grain intake is proven to have many health benefits. However, even though Swedish people on average could consume a bit more cereal and still be within the recommended range of energy from carbohydrates, it is not necessary for Swedish people to consume more cereals from a nutritional point of view. Nevertheless, if the cereals consumed were in whole grain form and of Swedish origin there would be multiple benefits. Those benefits include benefits for health, shorter transport distances of food, increased self-sufficiency in food products and less wastage of edible parts of the grain. In addition to increasing the consumption of cereals in Sweden, cereals produced in Sweden could to a larger extent be exported for use as food.

Another aspect when it comes to the nutritional part of the diet is that if the food system shifted towards a ‘livestock on leftover’ model it would probably mean that the Swedish population on average would eat less animal sourced food. According to the Swedish Food Agency Swedish adults on average consume a higher amount of meat than is recommended from a health perspective (Swedish Food Agency, 2020). Therefore, it would be a nutritional advantage for Swedish people to, on average, consume less meat. However, it is important to make sure that a diet provides a complete protein intake and essential nutrients (Swedish Food Agency, 2020). Cereals are lacking in two essential amino acids; lysin and threonine (Abrahamsson & Hambraeus, 2020). Furthermore, for example legumes contains both of those amino acids and when cereals are consumed together with legumes a complete protein intake is achieved. Animal sourced food normally has a surplus in essential amino acids and therefore just a small amount of animal protein is enough to supplement the amino acids in an otherwise vegetarian diet. By consuming various sources of food, even when excluding or limiting animal products, a nutritious and balanced diet can be achieved.

Historically, the Swedish population has got most of their calories from cereal products such as various forms of bread, porridge, gruel, palt or pancake (Leino, 2020). To increase the consumption of Swedish cereal products, the scientist and baker Karin Gerhardt thinks that we need to produce more Swedish alternatives to products that we import, such as pasta and rice (Gerhardt, 2020). For example, older varieties of grains have many other valuable qualities than just making flour. One example is “svedjeråg” (a type of rye) which could be used as an alternative to whole grain rice. There is also a possibility of producing a larger amount of pasta made from Swedish flour. The agronomist and researcher Matti Leino states that it would be interesting to see more products made of oats, rye, and barley (Leino, 2020). He thinks that Sweden has focused too much on wheat, and to produce products from other cereals would have both environmental and health benefits. In addition to this, the quality criteria of those grains are only limited to hygiene and dehulling ability since they are to a large exten used as food grain and groats.

Another alternative to increase human consumption of Swedish cereals is to develop new products. There are several examples of this, and one is a hamburger of spelt wheat and "gråärt", a kind of pea, produced by the cereal producer Niclas Dagman (Dagman, 2020). Spelt wheat has another type of gluten network and taste than wheat. Niclas Dagman is soon also launching a new taco mince and Bolognese made with spelt wheat as main ingredient. Another example of a new cereal product is Fazer mills' oat rice that won the Swedish Food price, 2020 awarded by the food industry network, Livsmedel i Fokus (Larsson, 2020).

However, there are many factors influencing which products customers choose to buy and eat. To be able to increase the consumption of Swedish grains, further research on consumers' attitudes, behaviour, and choices would be needed.

5.6. Sweden as a part of a global food system

Even though this thesis is limited to Swedish cereal production, the Swedish cereal market is connected to the world market and it is not possible to separate the two. Today, Sweden is a net exporter of cereals, meaning that the total production exceeds the total consumption (Swedish Board of Agriculture, 2019). With climate change the conditions for agriculture will change and the global available arable land will decrease. At the same time the global population is growing. This puts an additional pressure on the feed-food competition, and it is important to see that Sweden, as part of the future global food system, must use its arable land in the most effective way. To use the 'livestock on leftovers' model to do this is shown by research to be effective. For Sweden to be able to move its food system in the direction of 'livestock on leftovers' more research on the current situation and possibilities is needed.

6. Conclusion

Today most of the cereals produced in Sweden are used for animal feed. A large part of the cereals used as feed is of the quality needed to be used as food, even with current quality criteria. Furthermore, it is not necessary to use the same quality criteria as today in the future. This study shows that the most common quality parameters that fail to be reached, using current quality criteria, are protein level and falling number. Cereal that does not reach the current quality criteria for food can be considered left-over biomass, but they do not necessarily need to be. If cereals do not reach a high enough protein or falling number, they might not be suitable for flour but can still be used for other food products such as food grains (ex. wheat berry). The results of this study show that some of the quality parameter criteria for cereals for certain food products could, in the future, be lowered.

If a farmer aims to achieve food quality it is usually achieved, and if food quality is aimed for but not achieved it is mostly due to weather conditions, fungi, pests, and diseases. Some of the arable land in Sweden might not be suitable for production of high-quality food cereals, i.e., reaching current quality recommendations, but just how much is not known. One reason for this unsuitability is that some of the arable land contains high amounts of heavy metals, most commonly cadmium, which leads to trace elements of these in the cereals (Eriksson, 2020). A deeper analysis than possible in this thesis would be required to determine the exact extent of food grade cereals that could be grown instead of feed cereals in Sweden. To estimate the exact quantity of cereals that would unavoidably be classified as "ecological leftovers" (not suitable for human consumption) further research on cereal varieties' suitability for different climates would be needed. Varieties reaching food quality might be possibly be grown in certain areas where cereals are grown only for feed today. However, this study shows that the amount of cereals that can be considered truly a leftover biomass from growing cereals for human consumption is small.

It is important to see that Sweden is part of the global food system and that the use of arable land in Sweden does not only affect the country's food security but is a part of the whole world's food supply. Using the 'livestock on leftovers' model and increasing the amount of cereals grown for human consumption is proven to be an effective use of land. This study has shown that a greater quantity of cereals could be used for human consumption in Sweden. This would enhance the effectiveness of arable land and be a step towards a more sustainable food system.

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Appendix 1

	Durum wheat	Common wheat	Barley	Maize	Sorghum
A. Maximum moisture content (%)	14.5	14.5	14.5	13.5	13.5
B. Maximum percentage of matter which is not basic cereal of unimpaired quality (%)	12	12	12	12	12
1. Broken grains (%)	6	5	5	5	5
2. Grain impurities (%)	8.5	7	12	5	5
2.1 Impurities other than mottled grains (%)	5	7	12	5	5
(a) shriveled grains (%)	X	X	X	n.a.	n.a.
(b) other cereals (%)	3	X	5	X	X
(c) grains damaged by pests (%)	X	X	X	X	X
(d) grains in which the germ is discoloured (%)	X	X	n.a.	n.a.	n.a.
(e) grains overheated during drying (%)	0.50	0.50	3	0.50	0.50
2.2 Mottled grains (%)	3.5	n.a.	n.a.	n.a.	n.a.
3. Sprouted grains (%)	4	4	6	6	6
4. Miscellaneous impurities (%)	4.5[a]	3	3	3	3
of which:					

Figure 5. Minimum Requirements for Grain Traded Under Public intervention in the European Union Part 1.

(a) extraneous seeds					
— noxious (%)	0.10	0.10	0.10	0.10	0.10
— other	X	X	X	X	X
(b) damaged grains					
— grains damaged by spontaneous heating or too extreme heating during drying (%)	0.05	0.05	X	X	X
— grains affected with fusariosis (%)	1.5	X	X	X	X
— other	X	X	X	X	X
(c) extraneous matter	X	X	X	X	X
(d) husks (cob fragments in the case of maize)	X	X	X	X	X
(e) ergot (%)	0.05	0.05	n.a.	n.a.	n.a.
(f) decayed grains	X	X	n.a.	n.a.	n.a.
(g) impurities of animal origin	X	X	X	X	X
C. Maximum percentage of wholly or partially non vitreous grains (%)	27	n.a.	n.a.	n.a.	n.a.
D. Maximum tannin content[b] (%)	n.a.	n.a.	n.a.	n.a.	1
E. Minimum specific weight (kg/hL)	78	73	62	n.a.	n.a.
F. Minimum protein content (%, dry basis)	11.5	10.5	n.a.	n.a.	n.a.
G. Hagberg falling number (seconds)	220	220	n.a.	n.a.	n.a.
H. Minimum Zeleny index (mL)	n.a.	22	n.a.	n.a.	n.a.

Figure 6. Minimum Requirements for Grain Traded Under Public intervention in the European Union Part 2.

Appendix 2

Table 5.Maximum level of Mycotoxin allowed or recommended in cereal-based food items and feed in EU.

Mycotoxin	*Food-item*	*Maximum amount allowed (µg/kg)*
Alfatoxins	All cereals and all products produced from cereals with exception for processed cereal-based foods and baby foods for infants and young children and Dietary foods for special medical purposes intended specifically for infants	4.0
	Processed cereal-based foods and baby foods for infants and young children	0.1
	Dietary foods for special medical purposes intended specifically for infants	0.1
	Feed for dairy cattle and calves, dairy sheep and lambs, dairy goats and kids, piglets and young poultry	5
	Feed for cattle (except dairy cows and calves), sheep (except dairy sheep and lambs), goats (except dairy goats and kids), pigs (except piglets) and poultry (except young animals).	20
Ochratoxin A	Unprocessed cereals	5.0
	Unprocessed cereal products and processed cereals products aimed for direct consumption with exceptions for processed cereal-based foods and baby foods for infants and young children and Dietary foods for special medical purposes intended specifically for infants	3.0
	Processed cereal-based foods and baby foods for infants and young children	0.5
	Wheat-gluten, not sold directly to consumers	8.0
	Feed	250*
Deoxynivalenol	Unprocessed cereals with exception for durum wheat, oats and maize	1250
	Unprocessed durum wheat and oats	1750
	Cereals intended for direct human consumption, cereal flour, bran and germ as end product marketed for direct human consumption	750
	Pasta (dry)	750
	Bread (including small bakery wares), pastries, biscuits, cereal snacks and breakfast cereals.	500

	Processed cereal-based foods and baby foods for infants and young children Feed	200 8000*
Zeralenon	Unprocessed cereals with exception for maize. Cereals intended for direct human consumption, cereal flour, bran and germ as end product marketed for direct human consumption Bread (including small bakery wares), pastries, biscuits, cereal snacks and breakfast cereals Processed cereal-based foods and baby foods for infants and young children Feed	100 75 50 20 2000*
Ergot alkaloids	Unprocessed cereals except maize and rice 1 000 000	0,5g/kg 1 000 000
T-2 &HT-2*	Oats for direct consumption Other cereal for direct consumption Processed oat bran and oats Cereal bran other than oat bran, ground oat products other than oat bran and oatmeal and ground maize products Other grounded cereals Breakfast cereals including shaped cereal grains Bread (including small bakery wares), pastries, biscuits, cereal snacks and pasta Processed cereal-based foods and baby foods for infants and young children Feed	200 50 200 100 50 75 25 15 250

**Are only recommendations and not required by regulations*

Table 6. Maximum levels of metals and process contaminant in cereal-based food items in EU

Heavy metal	Food item	Maximum amount allowed (µg/kg)
Cadmium	Cereals and grain excluding wheat and rice	0.1
	Wheat and rice grains, wheat bran and germ for direct consumption	0.2
Lead	Cereals, pluses and legumes	0.2
Acrylaminde	Soft bread-wheat	0.05
	Non-wheat based soft bread	0.1
	Bran and whole grain cereal, gun-puffed grain, wheat and rye-based products	0.3

Table 7. Heavy metal limits in feed according to the Swedish Regulation, SJVFS 1993:177

Heavy metal	Feed	Limits (mg/kg) calculated on 12% water content
Arsenic	Cereals made from grass, from dried lucerne and from dried clover, and dried sugar beet pulp and complementary feeding stuff with exception of mineral feeding stuffs	4
	Phosphates and feeding stuffs obtained from the processing of fish and other marine animals	10
	Other feed materials	2
	Phosphates as feed materials	20
	Mineral feeding stuff	12
	Complete feeding stuffs for fish	4
	Other complete feeding stuff	2
Lead	Green fodder	10
	Phosphates	15
	Yeast	5
	Other feed materials	10
	Complete feeding stuffs	5
	Mineral feeding stuffs	30
	Other complementary feeding stuffs	10
Cadmium	Vegetable feed materials	1
	Animal feed materials	2

	Phosphates as a feed material Complete feeding stuffs Mineral feeding stuffs Other complementary feeding stuffs	10 1 4 0,5
Mecury	Feeds processed by fish or other marine animal Other feed materials	0.5 0.1

Appendix 3

Table 8. Interviewees of this thesis, their profession, employee , date and method for interview and the reason for the interview.

Interviewee	*Profession*	*Employed at*	*Date and method of interview*	*Reason for interview*
Victor Ebel	Responsible for cereals	Svenska Foder	Phone interview 2020-11-03 and follow up over email.	To understand Svenska Foders quality criteria.
Per Gerhardsson	Purchasing manager, Cereals	Lantmännen	Phone interview 2020-09-25 and follow up over email.	To understand Lantmännens quality criteria and general quality of cereals.
Karl Delin	Responsible for cereals	Varaslättens Lagerhus	Phone interview 2020-09-24 and follow up over email.	To understand Varaslättens Lagerhus´ quality criteria and general quality of cereals.
Mats Jönsson	Purchasing cereal manager	Swedish Agro	Email conversation 2020-12-18.	To understand Swedish Agros´ quality criteria and general quality of cereals.
Johan Gottfridsson	Plant cultivation consultant and EU consultant	Hushållningssällskapet	Phone interview 2020-10-09 and follow up over email.	To understand quality of cereals from a farming perspective and what influences

				what a farmer chose to grow.
Christina Hultman and Line Strand	Plant cultivation consultant organic production, Plant cultivation consultant and EU consultant	Hushållningssällskapet	Email interview 2020-10-13 with follow up questions	To understand quality of cereals from a farming perspective and what influences what a farmer chose to grow.
Ida Lindell	Plant cultivation consultant and EU consultant	Hushållningssällskapet	Email interview 2020-11-02 with follow up questions	To understand quality of cereals from a farming perspective and what influences what a farmer chose to grow.
Anders Pålsson	Plant cultivation consultant with main responsibility for market surveillance and cereal farmer	Hushållningssällskapet	Phone interview 2020-10-29 and follow up over email.	To understand quality of cereals from a farming perspective and what influences what a farmer chose to grow.
Jan Poulsen	Director Category Professional	Lantmännen	Interview over Microsoft Teams 2020-11-23 and follow up over email	To understand Lantmännens´ and their customers perspective of cereal quality and what quality attributes that are important when making different products

Employee at Oatly who which not to be reference. However, consent have been given to reference to Oatly.		Oatly	Email interview 2020-11-19 with follow up questions	To understand what quality parameters for Oats that are important to Oatly
Johan Karlsson	Food Engineer	Polarbröd	Phone interview 2020-11-20	To understand Polarbröds perspective on cereal quality
Jörgen Hansson, Niklas Jandergren, Anna Larsson	Sales and Development Manager, Sale manager and baker, Seed manager	Lilla Harrie Kvarn	Interview over Zoom 2020-10-27 and follow up over email	To understand Lilla Harrie Kvarns´ and their customers perspective of cereal quality and what quality attributes that are important when making different products
Anders Lööf	Quality and Technology Manager	Barilla Group	Email interview 2020-12-01 with follow up questions over email.	To understand Wasas´ perspective on cereal quality
Sébastien Boudet	Baker	CEO for the Craft Bakery Sebastién på Söder	Phone interview 2020-10-22	To understand craft baker's perspective on quality and how they differ from the bread industry
Kärsti Hård	Baker	CEO for the Craft Bakery Snitths Hantverksbageri I Furudal	Email interview 2020-11-02	To understand craft baker's perspective on quality and how they differ from the bread industry
Eva Johansson	Faculty professor and heading the	SLU	Phone intervies 2020-10-13 and	To understand how different cultivar of

	Plant Product Quality Research Group		follow up over email	cereals differs in quality attributes
Karin Gerhardt	Researcher in sustainable food systems, agriculture and bread history	SLU	Phone Interview 2020-10-16	To gain knowledge on ancient grains and on potential for increasing human consumption on cereals
Niclas Dagman	Cereal Farmer	Marcusgården	Phone Interview 2020-10-20	To understand quality of cereals from a farming perspective and what influences what a farmer chose to grow as well as his perspective on development new cereal products
Erik Hartman	CEO	Foder och Spannmål	Phone Interview 2020-09-14	To get and overview of the cereal industry
Patrik Eklöf	Agriculture Policy Investigator	Swedish Board of Agriculture	Email contact 2020-12-18	To get access to and understand the statistics about cereal usage
Peter Friberg	Purchasing manager cereals	Saltå Kvarn	Phone interview 2020-12-16	To understand Saltå Kvarns´ perspective on cereal quality
Matti Leino	Researcher at The Department of Archaeology and Classical Studies, Stockholm University	Stockholm University	Email interview, 2020-10-15	To get a cereal researcher perspective on possibilities of increasing cereal consumption.

Appendix 4

Explanation of quality criteria used by Lantmännen, Varaslätten-s Lagerhus, Swedish Agro and Svenska Foder (Lantmännen, 2020) (Swedish Agro, 2020) (Svenskt Foder, 2020) (Varaslättens Lagerhus, 2020).

Water content- A water content below 14% is usually desired since moisture limits the shelf life of the final product (Blakeney et.al. 2009).

Protein content- The protein content required depends on the end-product (Blakeney et.al. 2009).

Density- A low density means that each kernel is surrounded by more hull than if the density is higher (Delin, 2020). A high density is desired since this gives a higher milling yield.

Foreign grains- Not desired but accepted in small quantities (Lantmännen, 2020) (Swedish Agro, 2020) (Svenskt Foder, 2020) (Varaslättens Lagerhus, 2020).

Green kernels- Means that the kernels are not mature enough to be harvested (Delin, 2020). A high number of green kernels indicates an uneven harvest.

Smashed or animal eaten kernels- Not desired but accepted in small quantities (Lantmännen, 2020) (Swedish Agro, 2020) (Svenskt Foder, 2020) (Varaslättens Lagerhus, 2020)..

Wild Oat- is a kind of weed that is hard to eradicate (Brittanica, 2020)

Germinated kernels- During germination, the starches in the seeds starts to get broken down to simple sugars (Newberry et.al., 2018).

Falling number (what, rye & barley)- The falling number test measures the amounts of activity of the enzyme α-amylase in the kernel as well as the starch quality (Newberry et.al., 2018). α -amylase degrades starch into simple sugar during the germination of the seed. Kernels with higher moisture levels usually exhibits higher levels of α-amylases, this is because high rainfall can cause the grain to germinate pre-harvest.

Colour (oats)- Oats can get infected by an unharmful fusarium species that give the oats a greyish colour (Delin, 2020). Even though the fungi infection does not result in production of any harmful mycotoxins it can give an off taste which is not desired. Colour is also a quality parameter since lighter groats are consider more visual pleasing for consumers (Strychar, 2011).

Appendix 5

Popular Scientific Summary

A large part of Swedish cereals used as feed for animals could be eaten as food directly by us humans. This is one of the findings of the master thesis: Cereals as 'leftover biomass'- *An analysis of Swedish cereal production from the perspective of feed-food competition.* Imagine a world where the population has increased to over 10 billion people. At the same time, climate change has led to a large extend of the agriculture land not being arable anymore, which, together with the population growth, have led to a widespread food insecurity. This world might not be far from the future we are facing. To minimize the risk of this future scenario is important to use our agricultural land as effectively as possible to ensure food security and minimize environmental impacts.

In this thesis the Swedish cereal production has been analysed from the perspective of feed-food competition. The concept of feed-food competition refers to the use of land for producing crops for feed rather than for crops for direct human consumption. Currently livestock production uses 70% of the arable land and 40% of the arable land is used for feed production. In addition to this livestock accounts for 60% of the global greenhouse gas emissions from the food system. Since the 1960s meat consumption has increased drastically on a global level. Expansion of livestock production has led to an increasing demand for land. To meet the demand, forest and native grassland has been converted into agricultural land which has led to biodiversity loss and increased greenhouse gas emissions. To eliminate feed-food competition the amount of crops produced direct for human consumption must increase. If this would be achieved, the land would be used more effectively, which is necessary, considering the earlier mentioned future scenario we are likely to face.

A common argument why crops produced is used for feed instead of food is that they do not keep food quality. To investigate if this was true interviews with 22 people were conducted with working with Swedish cereals and cereal production. The usage of Swedish cereals together with what quality criteria that are used was also investigated through data collection. The reason why cereal production was analysed in this thesis is that cereal is a common agricultural crop that are used both for feed and food. The result showed that the earlier presented argument; that cereals are used for feed because they do not keep food quality, is a myth. Most of the cereals produced in Sweden is used for feed but a large extend of the cereals used as feed keeps food quality.

Another finding of this study is that the current quality criteria, used for classifying cereals of food quality, might be set unnecessary high for some cereal food products. For example, in order to classify whether wheat reaches food quality, the high quality required for milling wheat (used for wheat flour) must be met. When producing wheat flour the protein content is important since it contributes to the baking quality of flour. However, wheat can also be used to for example, wheat berry. When producing wheat berry the protein content is not of importance. Wheat grains that are hygienic and sound but not rich in protein is today classified as feed wheat even if it could be used for food products such as wheat berry.

However, some of the agricultural land in Sweden might not be suitable for growing cereals of food quality. There are several reasons for this such as unsuitable climate and unfertile soil or a combination of these. Some areas might have a high content of heavy metals in the soil and since cereals takes up heavy metals from the soils it is not suitable to grow cereals for food in those regions. For feed cereals a higher amount of heavy metals are allowed and because of this cereals for feed can be grown on those soils. The point of departure of this thesis is not that we should erase the production of livestock, but that we should limit the feed of livestock to products that human cannot or do not want to eat. If we would use this production system, a sustainable diet would include animal sourced food but to a lesser extend than most diets do today. As long as this kind of diet includes food from various food sources, it would also be beneficial from a health perspective.

Even though this thesis is limited to Swedish cereal production, the Swedish cereal market is connected to the world market and it is not possible to separate them. With climate change the conditions for agriculture will change and the global available arable land will decrease. It is therefore important that we use the arable land that we have as effectively as possible. This study has shown that a greater quantity of cereals could be used for human consumption in Sweden. This would enhance the effectiveness of arable land and be a step towards a more sustainable food system.