Blue lupin in a food value chain

Based on vegan and organic lupin ice cream, sourced and produced in Sweden

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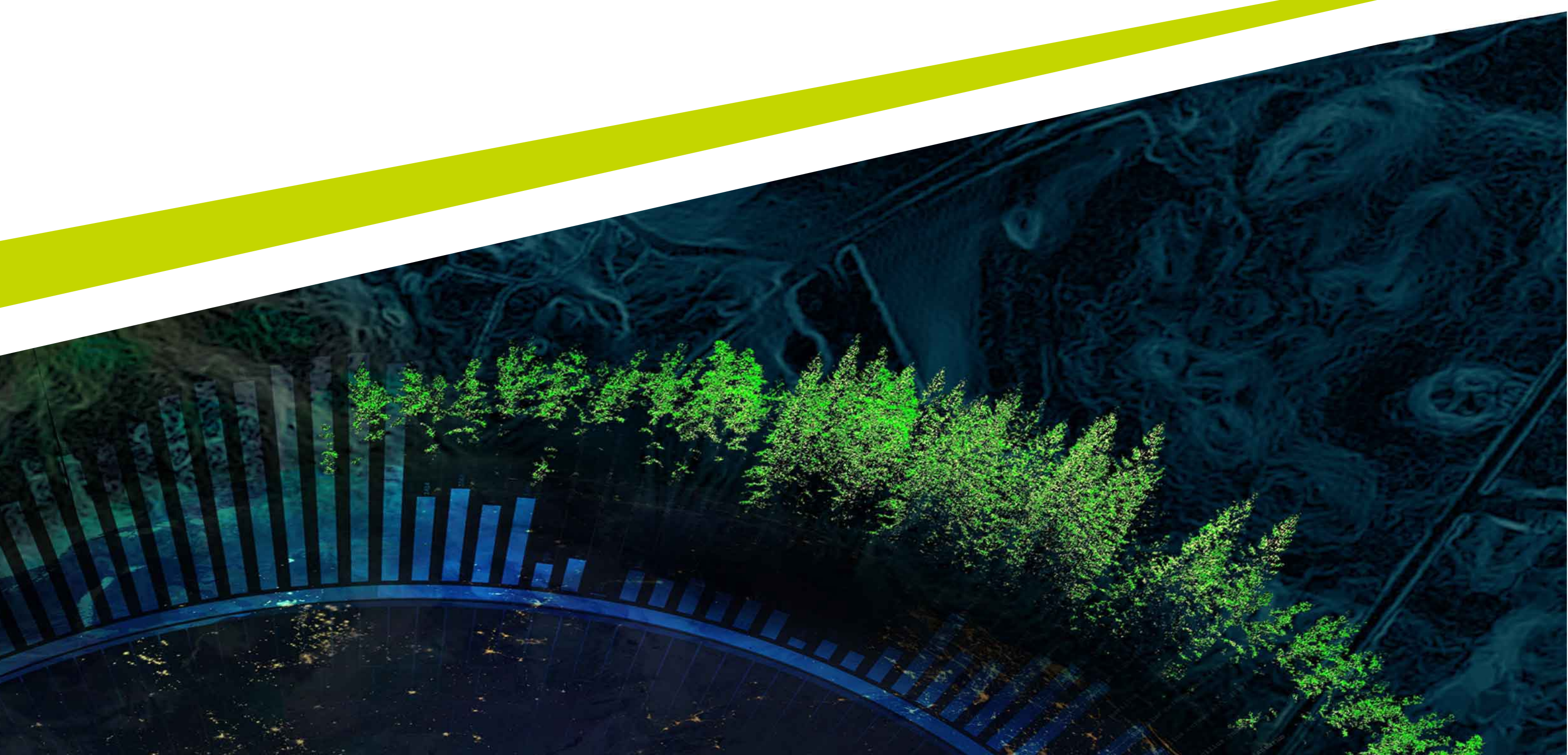

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Abstract

Global food systems need to undergo drastic changes to decrease greenhouse gas emissions and increase the sustainability in all aspects – environmentally, socially, and economically. The COVID-19 pandemic and the war in Ukraine have shown how sensitive the global food systems are to disruptions, as many countries depend on food imports. To increase food security and the sustainability of our food systems, there is a need to promote local food value chains and change to a more plant-based diet. This project has a broad view on the food value chain around vegan and organic lupin ice cream that is sourced and produced in Sweden, where cultivation of blue lupin, processing of lupin seeds and financial aspects regarding these two parts are considered. To assess the processing part, protein was extracted from lupin seeds and used to make lupin ice cream. A sensory analysis was carried out to determine if the ice cream production had been successful.

The literature study showed that it is possible to grow blue lupin with good results in Sweden, especially in the south of Sweden, both in terms of yield and farm income. Blue lupin is valued as a break crop with a high protein content that can be grown as an alternative, or as an addition, to field peas (*Pisum Sativum)* in Swedish crop rotations, due to a low pest and disease pressure. There is no need to fertilize blue lupin as the deep roots take up the P and K needed and the biological nitrogen fixation is high. The deep roots improve soil structure and this together with the high nitrogen fixation makes it a good pre-crop for the next crop. The drawbacks of growing blue lupin are mostly connected to the start-up phase of the cultivation, as there is a steep learning curve on how to manage this, to most growers in Sweden, new crop. The cost of seeds and the need for inoculation when sowing lupin for the first time is also a drawback for some farmers.

Protein was successfully extracted from lupin seeds and used as a base for vegan ice cream. Only Swedish and organic ingredients were used for the lupin ice cream and resulted in three different flavours: Raspberry, strawberry and elderflower. Both taste and texture got good scores for all three flavours during the sensory analysis, showing the potential of a new product. The lupin ice cream is different from most other ice creams on the Swedish market, offering a new sustainable alternative. By using local ingredients, the processing part of the food value chain is less dependent on imports, and by using ingredients that are both local and organic, the production part of the food value chain becomes less dependent on imports as well. Since only the protein is extracted from the lupin seeds, more research is needed to find a use for the rest of the seed. There is also a high water usage for extracting the protein that needs to be optimized.

With a normal to high grain yield, blue lupin has the potential of being one of the better organic crops in terms of gross margin when it is used for human consumption. There is also a potential for increased margins once the cultivation is more established. Further development is needed to reach a more reasonable retail price for the lupin ice cream, as the premium combination of Swedish and organic ingredients gives it a higher price than most potential competitors, and therefore likely exceeds consumers' willingness to pay.

Keywords: Lupin, value chain, local, organic, vegan, ice cream

Sammanfattning

Globala livsmedelssystem behöver drastiskt förändras för att minska utsläpp av växthusgaser och öka hållbarheten i alla aspekter – miljömässigt, socialt och ekonomiskt. COVID-19 pandemin och kriget i Ukraina har visat hur känsligt det globala livsmedelssystemet är för störningar, då många länder är beroende av importerade livsmedel. För att säkra försörjningen av livsmedel och öka hållbarheten på livsmedelssystemen, så finns det ett behov av att främja lokala värdekedjor och byta till en mer växtbaserad diet. Detta projekt ger en överblick av en värdekedja kring vegansk och ekologisk lupinglass som är producerad i Sverige med svenska ingredienser, där odling av sötlupin (*Lupinus angustifolius*), processning av lupinbönor och ekonomin kring dessa två delar tas i beaktande. För att bedöma processningsdelen extraherades protein från lupinbönor och användes till att producera lupinglass. En sensorisk analys utfördes för att avgöra om produktionen av lupinglass hade lyckats.

Resultat från en litteraturstudie visar att det går att odla sötlupin med goda resultat i Sverige, speciellt i södra Sverige, både vad gäller skörd och inkomster till gården. Sötlupin värdesätts som avbrottsgröda med högt proteininnehåll som kan odlas som ett alternativ, eller som ett tillägg, till ärtor (*Pisum sativum*) i växtföljden, tack vare ett lågt sjukdoms- och skadedjurstryck. Det finns inget behov av att gödsla sötlupin då djupa rötter tar upp det P och K som behövs och kvävefixeringen är hög, näring som forslas bort med skörden ersätts med fördel genom att gödsla en annan gröda i växtföljden. De djupa rötterna förbättrar jordstrukturen och detta tillsammans med den höga kvävefixeringen gör sötlupin till en bra förfrukt. Potentiella hinder för odling av sötlupin är till stor del kopplade till starten av odlingen, då odlaren behöver lära sig hantera en gröda som för de flesta odlare i Sverige är en helt ny gröda. Kostnaden för utsädet och behovet av ympning när sötlupin ska sås på nya fält är också nackdelar, men sparas en del av skörden så blir kostnaden för utsäde mindre redan nästa säsong, och behovet av ympning minskar också med tiden.

Protein extraherades med bra resultat från lupinbönor och användes som en bas till vegansk glass. Endast svenska ekologiska ingredienser användes till lupinglassen och resulterade i tre smaker: Hallon, jordgubb och fläderblom. Både smak och konsistens på alla tre smaker fick bra betyg under den sensoriska analysen, vilket visar potentialen för en ny produkt. Lupinglassen är annorlunda än de flesta andra glassar på svenska marknaden och erbjuder ett hållbart alternativ. Genom att använda svenska ingredienser kan processningsdelen av värdekedjan bli mindre importberoende, och genom att använda svenska ekologiska ingredienser så blir även odlingsdelen av värdekedjan mindre importberoende. Eftersom endast proteinet extraherades från lupinbönorna, så behövs mer forskning kring vad övriga komponenter från lupinbönan kan användas till. Vid proteinextraktionen används också en stor mängd vatten, något som behöver optimeras.

Med en normal till hög fröskörd, har sötlupin potentialen att vara en av de bättre ekologiska grödorna vad gäller bruttomarginal, när bönorna används för humankonsumtion. Det finns även potential till att öka marginalerna när odlingen är mer etablerad. Lupinglassen behöver utvecklas ytterligare för att få ner försäljningspriset till en rimlig nivå, kombinationen av svenska ekologiska ingredienser resulterar i ett pris som är högre än många konkurrenters, och därmed sannolikt överstiger vad konsumenter är villiga att betala.

Nyckelord: Sötlupin, värdekedja, lokal, ekologisk, vegansk, glass

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1. Introduction

In 2021 the world population reached 7.9 billion (United Nations Population Fund, 2022), and it is expected to reach 9.7 billion by 2050, and 10.9 billion by 2100 (Population Matters, 2022a). With an ever-growing world population, what we choose to eat, especially in high-income countries, will have more and more of an impact on several different levels, both environmentally, socially, and economically (Lindgren et al., 2018; Lucas & Horton, 2019; Strid et al., 2021; Population Matters, 2022a,b). It is possible to feed 10 billion people in a sustainable way with the resources that are available, but in order to do so; a large part of the world's population will have to drastically change their diet to a more plant-based diet (Lucas & Horton, 2019). In high-income countries, the intake of meat, especially red meat, needs to be reduced by at least 50% in order to reach a sustainable diet (Röös et al., 2018; Lucas & Horton, 2019). Legumes have been suggested as a viable substitute for meat, as it is beneficial for human health, the climate and the environment (Lucas et al., 2015; Röös et al., 2018). Sweden as well as Europe imports large quantities of soy that is mostly used as feed, but as soy often is grown under conditions that harm nature and people, local alternatives to imported soy, such as blue lupin (*Lupinus angustifolius*), have been suggested (Lizarazo et al., 2015; Lucas et al., 2015; Swensson, 2015). If legumes are grown domestically, they can reduce the need for feed and meat import and support the local food value chain, as well as increase the food security within the country (Röös et al., 2018; FAO, 2020).

2. Objective and aim

The overall aim of this study is to investigate how blue lupin (*Lupinus angustifolius L.*) can be used in Sweden as a complement to other protein crops by looking at a new food value chain evolving around lupin-based ice cream. This interdisciplinary thesis intends to cover several aspects such as the cultivation suitability and agronomic management of lupin in Sweden, the technological possibilities for processing lupin into ice cream, and the financial viability of lupin production and processing. Technological possibilities for processing lupin seeds will be evaluated by making lupin ice cream with different recipes in order to create a viable product that can be sampled at the end of the project. The environmental and dietary benefits of choosing to eat lupin based vegan ice cream, compared to other vegan and dairy based ice creams, will also be discussed. This work aimed at assessing the viability of a 100% plant-based, organic and domestically produced ice cream.

The objective of this work is to investigate the viability of growing lupin for human consumption by assessing the food value chain of organic, vegan and locally sourced lupin ice cream in a Swedish context, using the following research questions:

- What are the potential benefits and drawbacks of lupin cultivation in Sweden?
- Is it technologically and financially viable to use lupin as a base for vegan ice cream?

In this work, the food value chain will be defined as a sequence of components starting at the natural resources base (soil, water, nutrients), followed by the production (cultivation), storage, processing, trading and finally consumption. The main components that will be addressed in this work are the production, processing, and trading.

The outcomes of this activity should indicate the agronomic, technological and economic feasibility of domestic cultivation of lupin.

3. Background

The following sections will provide a background about sustainable food systems and how legumes, and specifically lupin, can contribute to a more sustainable food system in Sweden by using it for plant-based food such as vegan ice cream. The background is based on a review of articles found mainly through the search engine Primo, provided by SLU library, and through Google Scholar. The topics searched for were chemical composition of blue lupin, tillage, erosion, organic farming, manure shortage, legumes, sustainable food systems and various combinations of these words. By looking at the references of some of the key articles, more articles of relevance were found. International and governmental sources such as FAO and the Swedish Board of Agriculture were used to find harvest data, information about market shares and current information on agricultural practices.

3.1 Sustainability of food systems

Recent data show that food systems on a global scale contribute with around one third of all anthropogenic greenhouse gas (GHG) emissions, where the biggest contribution comes from the production of livestock and crops (Tubiello et al., 2021). In modern food systems, it is common practice to use large amounts of inputs on our fields by means of fossil fuel and fertilizers, then give crops that could have been eaten by humans to feed farm animals, transport the food long distances (Ericksen, 2008), and then despite all that effort, one third of all food produced ends up being lost or wasted (FAO, 2022a). This inefficient use of resources cannot continue if we are to feed 10 billion humans in the future. High-income countries play an important role in changing the current food system to a more sustainable one, as 2/3 of the GHG emissions from food systems are derived in high-income countries (Tubiello et al., 2021). Sweden has the potential of becoming self-sufficient on staple food items and at the same time reduce the climate impact of food production by 90% (Granstedt & Thomsson, 2022).

Strid et al. (2021) investigated the climate and health impact of common food items in Sweden by comparing CO_2 emissions and nutrient density for each food item. Cream based ice cream has according to that study a lower nutrient density than the median food item and the climate impact is right on the median value or slightly above depending on the reference point. Food items with a lower climate impact and a higher nutrient density when looking at CO_2-eq/100kcal are for example legumes, vegetable oils and root vegetables (Strid et al., 2021). Berries have one of the highest nutrient densities but because of their low calorie count the CO_2-eq/100kcal ends up a fair bit higher than many of the other food items (Strid et al., 2021). All of the food items just mentioned were used to produce vegan lupin ice cream in this project.

Karlsson and Röös (2019) have developed a scenario where a regional food system in Norway, Sweden, Denmark, and Finland, was based on organic agriculture where food-feed competition is avoided by limiting livestock production to the regional availability of leftover streams and semi-natural grasslands as feed. By avoiding food-feed competition, reducing food waste, and by altering our diet to a more plant-based diet, Karlsson and Röös (2019) showed that it is possible to produce complete diets for up to 37 million people in the Nordic region, which is 8.6 million more than what is expected to be needed by the year 2030.

3.1.1 Plant-based food

When livestock is fed with grains that could have been eaten by humans, energy will be lost through metabolic processes. So instead of humans eating 1 kg of grain dry matter, farm animals such as poultry, fish, pigs, sheep and cattle would have to eat approximately 1.5, 2, 3.1, 5 and 12.5 kg of grain as feed, respectively, to produce 1 kg of meat for human consumption (Agri Farming, 2019; Karlsson and Röös, 2019). Because of the feed conversion ratio, a much larger amount of land is needed to produce animal sourced food than plant-based food. Food-feed competition is difficult to avoid with monogastric animals such as poultry and pigs, but cattle and sheep are ruminants and can therefore eat grass and herbs from semi-natural grasslands where other crops cannot be cultivated (Karlsson and Röös, 2019).

In order to reach a sustainable diet, high-income countries such as Sweden will have to decrease their meat consumption by at least 50% (Röös et al., 2018; Lucas & Horton, 2019). Figure 1 shows the main food items consumed in Sweden per person and year, and the preliminary numbers for 2019 show that meat accounted for around 82.5 kg (1.58 kg/week or 0.23 kg/day) that year. The Swedish National Food Agency recommend to not eat more than 0.5 kg of red meat and charcuterie (beef, pork, sheep, deer and game meat) per week from a health perspective (Livsmedelsverket, 2022). One of the recommendations that the Swedish National Food Agency give is to exchange some of the meat for legumes, as legumes are a good option both for our health and the environment (Livsmedelsverket, 2022). Changing our diet to a more plant-based diet would have positive effects on climate change, land use, food security, resource efficiency and more, as the majority of the agricultural sector will be affected by what consumers eat and the demand that they create (González et al., 2011; Röös et al., 2018; Lucas & Horton, 2019; Tälle et al., 2019). Röös et al. (2018) show that it is viable to reduce the Swedish meat intake by replacing it with domestically grown grain legumes, both in terms of nutritional recommendations and land use within Sweden. Note that this is only a reduction and not a complete replacement, as ruminants contribute with many vital and important ecological services such as manure for fertilization and open landscapes with high biodiversity as an effect of their grazing (Nilsson et al., 2013; Waldén & Lindborg, 2016).

During the past ten years, the interest for vegetarian food among Swedish citizens has steadily increased each year according to an annual survey, but in 2021, the interest declined for the first time since the survey started (Larsson, 2021). Fewer people now define themselves as flexitarians, vegetarians and vegans compared to the survey done in 2020. This is believed to be because of the recent pandemic, an insecure time that likely made people resort to comfort food, food that they used to eat as kids, which brings a sense of security (Larsson, 2021). The reason for eating vegetarian food has however shifted a bit and more people now eat vegetarian to benefit the climate rather than to benefit their health (Larsson, 2021).

This can be seen on the Swedish ice cream market, where the selection of vegan alternatives to traditional ice cream continues to increase, following the demand from consumers that want more environmentally friendly options (Svenska Dagbladet, 2019; Enquist, 2022). There is a need for healthier dessert options, as WHO reports that 59% of all adults in Europe are overweight or obese (Sjögren, 2022). Many ice cream companies therefore offer alternatives with no added sugar or less added sugar as part of their sustainability approach (Lagerqvist, 2019).

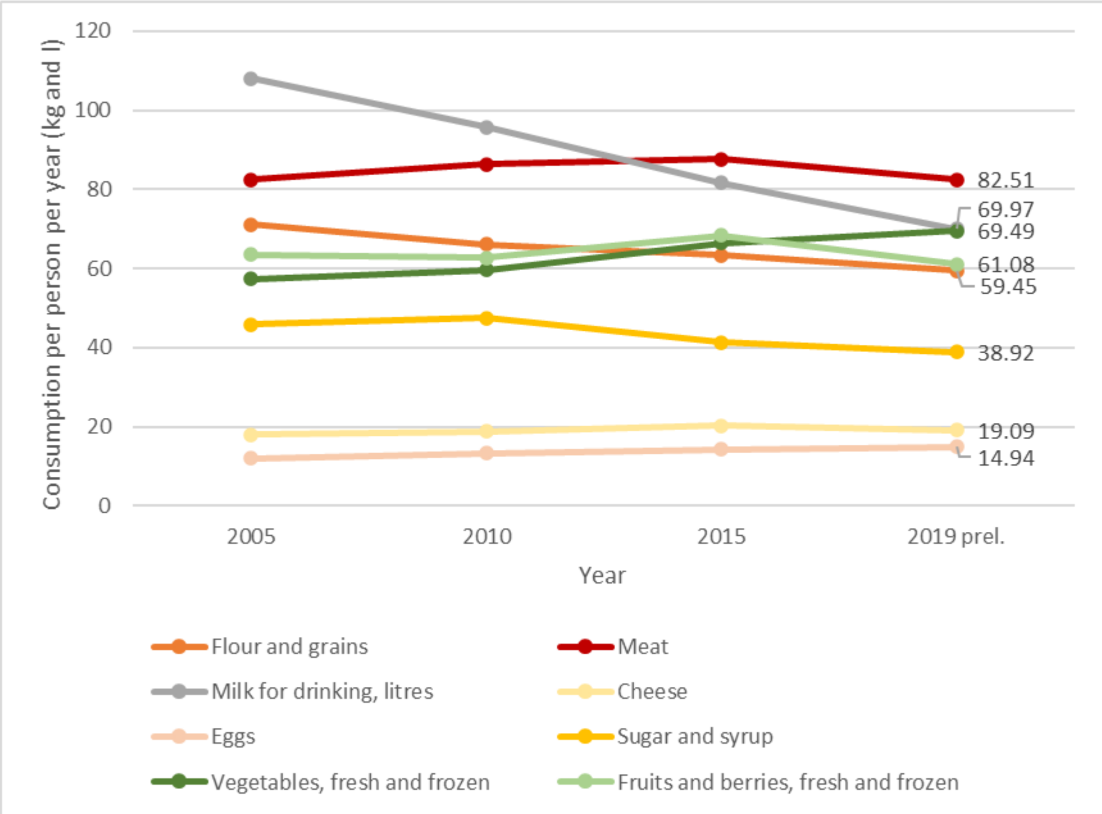

Figure 1. Total consumption of main food items in kilos or litres per person and year in Sweden, data from Jordbruksverket (2021a).

3.1.2 Local versus imported food

The Food and Agricultural Organization of the United Nations (FAO) have raised the importance of supporting local food producers in order to increase the national food security. Many countries have until now been highly dependent on imported food, but with the COVID-19 pandemic, many global food systems were disrupted as borders closed to stop the spread of the disease (FAO, 2020; Wunderlich, 2021). Closed borders meant that a lot of food could not be delivered to their final destination, causing both food loss and waste as well as decreased food security. The food security in Sweden was up for discussion by the civil defence even before the pandemic, looking at how Swedish farming would be vulnerable to major disruptions and how these vulnerabilities can be mitigated (Eriksson et al., 2020). Following the COVID-19 pandemic, the war between Russia and Ukraine has further shown the vulnerability of our food systems. Ukraine is one of the world's biggest producers of sunflower oil with 41% of the global market, and they produce a large share of the world's traded barley, wheat, and maize (Weil & Zachmann, 2022). The war has caused severe displacement of the Ukrainian population and it has been estimated that as much as one third of their agricultural land will not be cultivated or harvested because of the displacement of the Ukrainian population (FAO, 2022). Not only will the war affect the food supply for the Ukrainian people, but also the countries that rely on Ukraine to produce the crops mentioned (FAO, 2022). By promoting local food production, the risks of food insecurity can be reduced and the resilience of local food systems increased (FAO, 2020).

When looking at market shares, Sweden is only self-sufficient for cereals, carrots and sugar, and overall Sweden has a self-sufficiency of around 50% (Lantbrukarnas Riksförbund, 2021; Jordbruksverket, 2022b). This is however only true when the agricultural inputs needed for the production are not taken into consideration. If fuel, fertilizers, feed and agricultural machines are taken into account, then the self-sufficiency would be considerably lower (Kihlström, 2020; Jordbruksverket, 2022b). The need to import food and agricultural inputs in Sweden could be reduced to a large extent if the food system in place would change to a more resource-efficient system as suggested by Karlsson and Röös (2019) and Eriksson et al. (2020).

A common understanding is that the environmental sustainability of imported food is much lower compared to food produced locally due to the amount of transportation needed to import food, but there is a large variability between different products depending on how and where they were produced and how far consumers travel to purchase the products (Niles et al., 2018; Tidåker et al., 2021). In terms of mitigation of GHG emissions, limiting transportation has some effect, but not as much as changing the diet from non-vegetarian to vegetarian (Tälle et al., 2019). Choosing locally or domestically produced food can on the other hand contribute to social and economic sustainability for both the producers and the nation as a whole, due to increased food security (Gruvaeus & Dahlin, 2021; Tälle et al., 2019; FAO, 2020).

Buying locally produced food in Sweden is since 2016 a lot easier thanks to local food networks called REKO-rings (Gruvaeus & Dahlin, 2021). Each REKO-ring is connected to a local area and is organized in an informal way where farmers post what they have on offer once every two weeks in the Facebook-group of their local REKO-ring. The first REKO-ring in Sweden started in 2016, and five years later the amount of REKO-rings has grown to around 220 with about 800,000 members (Hushållningssällskapet, 2021a; Gruvaeus & Dahlin, 2021).

3.2 Organic food production

Sweden has one of the world's largest shares of organic farmland, with 20.4% of all farmlands under organic management (FiBL, 2022). This can be compared to the European average, which was 3.7% in 2020. The organic market share grew immensely around the world in 2020, in Sweden there was a small increase in 2020 which decreased again in 2021, so the Swedish trend does not quite follow the global trend (Ekologiska Lantbrukarna, 2022; FiBL, 2022). The organic market share in Sweden has decreased from the peak of 7.9% in 2016 to 6.9% in 2021 (Ekologiska Lantbrukarna, 2022). The large proportion of organic farmland in Sweden is not reflected in the organic market share due to a large fraction of the land being used as pasture and ley for production of feed (Jordbruksverket, 2022c). There is also a yield gap between organic and conventional food production, which means that a larger amount of land is needed for the organic food production compared to producing the same amount of food with conventional methods (Kirchmann, 2019).

Organic farming in a broad sense means that the farmer only uses organic seeds, fertilizers are of natural origin such as manure, their crop rotation is very varied to keep diseases, pests and weeds at bay, but also to keep the soil healthy by adding organic matter (Jordbruksverket, 2022a). Synthetic chemicals such as herbicides, pesticides and fungicides are not allowed, which is one of the reasons why a well-planned crop rotation is very important together with mechanical weeding and other alternatives to maintain a good yield. If the organic farmer has animals in their production, then a large proportion of their feed must be organic feed from the farm, the livestock must be allowed outside, and when they are in a stable they should be able to have a natural behaviour (Jordbruksverket, 2022a).

In general, organic food production produces less energy per hectare compared to conventional farming (Connor, 2022); despite that, it is possible to produce more than enough food for everyone in Sweden using only organic farming on already existing farmland, but Swedes would have to accept a more plant-based diet compared to what they are used to (Karlsson & Röös, 2019). Switching to organic farming instead of conventional would make Swedish agriculture less dependent on importing synthetic fertilizers and chemicals, which is positive for the resilience of Swedish food systems (Macfadyen et al., 2015; Karlsson & Röös, 2019). As synthetic fertilizers are not used in organic farming, the need for manure is great and many organic farms are dependent manure from neighbouring conventional farms in order to have enough nutrients for their crops (Kirchmann et al., 2016). Without the use of chemicals to control weeds, organic farms are also highly dependent on tillage to control weeds, which increases the use of fuel and can cause soil erosion (Peigné et al., 2007). To avoid soil erosion and excessive fuel usage, it is recommended for organic farms to practice conservational tillage where possible (Peigné et al., 2007). Organic agriculture also helps to increase species abundance and richness on a field scale, compared to intensely managed conventional fields, when it comes to soil organisms, plants, predatory insects, and birds (Bengtsson et al., 2005; Tuck et al., 2014). However, the scale of the land investigated matters greatly when comparing biodiversity on conventional versus organically managed land (Tuck et al., 2014). There is also the question of whether the holistic farming approach that organic farming provides is better for biodiversity, or if smaller areas dedicated to biodiversity on farms with conventional management would provide the same amount of benefits (Hole et al., 2005).

Legumes are imperative to organic cropping systems because they offer a break from cereals and other crops as well as adding nitrogen to the soil through the fixation of atmospheric N_2 (Jordbruksverket, 2004; Fogelfors, 2015; Lizarazo et al., 2015).

3.3 Blue lupin (*Lupinus angustifolius L).*

Figure 2. A photo of two mixed cultivars of blue lupin, Lupinus angustifolius L, one with white flowers and one with blue flowers. Photo by: Marcos Lana.

Blue lupin (*L. angustifolius*), also called narrow-leafed lupin, is a legume and part of the Fabaceae family together with crops such as field peas, lentils (*Lens culinaris Medik.*) and soybeans (*Glycine max (L.) Merr.*) (Stoddard, 2017; EFSA, 2019). Blue lupin can have either blue or white flowers depending on the cultivar (Figure 2). The cultivated varieties of lupin are called 'sweet lupins' because of their low amount of alkaloids (<0.02%); wild lupins, on the other hand, can have as much as 5% of alkaloids, resulting a bitter taste and high toxicity (Wink, 1988; EFSA, 2019). Selective breeding has thus made lupins edible for humans, something that is not possible with wild lupins (Sweetingham & Kingwell, 2008; Hickisch, 2020). Australia is by far the biggest producer of lupin seeds in the world, and in Europe Poland, the Russian Federation and Germany are some of the main producers (Figure 3).

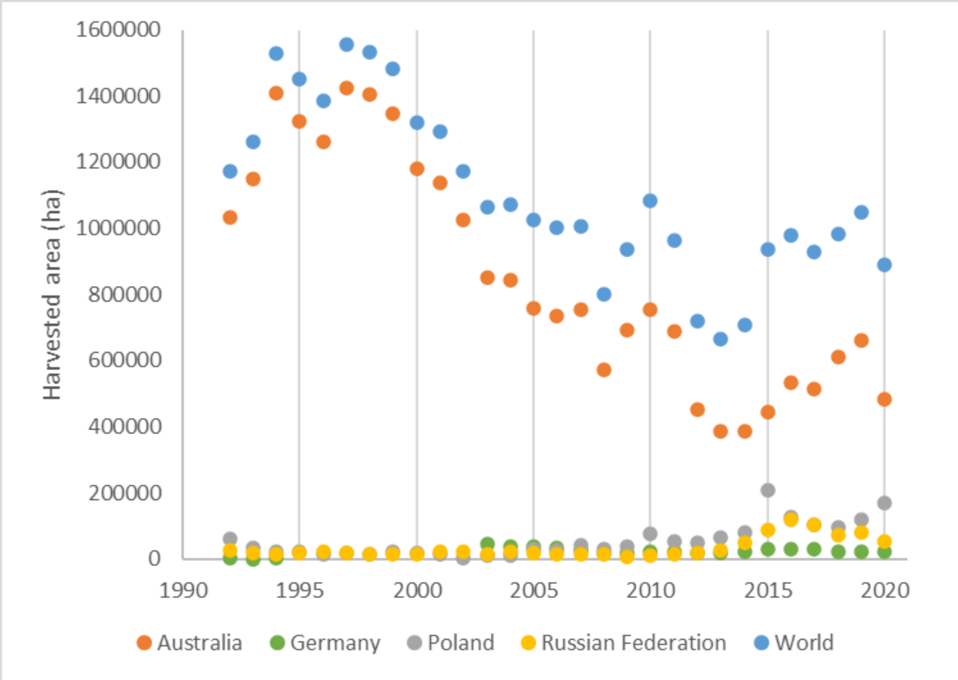

Figure 3. Harvested area of lupin (all cultivated varieties) in ha shown year by year from 1992 to 2020. (FAOSTAT, 2022).

During 2020, lupin was grown on around 185 hectares in Sweden, a small amount compared to the 20,000 hectares of field beans grown in Sweden (Karlsson, 2020). Like all legumes, lupins are able to fix atmospheric nitrogen by the roots with help from rhizobia, and the nitrogen that is left in the soil after harvest can increase the yield of the following crop (Evans et al. 1989; Peoples et al. 2009; Baddeley et al., 2013; Williams et al., 2014). On average, lupin fixes considerably more nitrogen than field peas that are grown in similar conditions (Table 1), this can however vary a lot as it depends on how much biomass the crops produce (Evans et al., 1989).

Table 1. Average nitrogen fixation and soil N contribution in kg N/ha for field pea (Pisum sativum) and lupin (Lupinus angustifolius) grown in similar conditions with comparison of protein contents. (Evans et al., 1989; Sujak et al., 2006; Murphy-Bokern et al., 2017)

	Field pea	**Lupin**
Protein content	25%	33%
Nitrogen fixation kg N/ha	80	98
Contribution to soil kg N/ha	18	38

Compared to other cultivated lupin species such as yellow (*L. luteus L.*) and white lupin (*L. albus L.*), blue lupin has a higher resistance against the fungus *Colletotrichum lupini* that causes anthracnose (a plant disease that destroys the whole plant), it is more frost tolerant and has a shorter growth period which makes it suitable for Nordic conditions (Fogelfors, 2015; Muranyi, 2017; Hickisch, 2020; Książkiewicz et al. 2022).

Blue lupin has been cultivated in high latitudes such as in Canada (Williams et al., 2014) and as far north as Umeå in Sweden with successful results, the growing season is however shorter in Umeå which compromises the yield (RISE, 2019). The small amount of lupin currently cultivated in Sweden is mostly in the southern part of the country, as the probability of a successful growth and harvest is higher due to the longer seasons and warmer climate (Stoddard, 2017; Andersson, 2020). There is also the choice of branched and unbranched varieties of lupin, which affects the time it takes for the seeds to mature. Branched varieties need two to three weeks more to mature compared to unbranched varieties because of the uneven maturation of the seeds on the branches (Jordbruksverket, 2004; Gresta et al., 2017). For this reason, the branched varieties are best suited for the most southern parts of Sweden and the unbranched varieties can be cultivated with good results even in parts of Svealand (Jordbruksverket, 2004; HIR Malmöhus, 2011; Stoddard, 2017). Blue lupin grows well where most other crops would not, which is on sandy soil, or soil with less than 10% clay, that is slightly acidic and with poor nutrient status (French, 2016; Gresta et al., 2017). Lupin can be a positive contribution to annual crop rotations as modern cultivars will give a good yield, the deep roots will improve the structure of the soil, the efficient nitrogen fixation will leave more nitrogen in the soil than field peas would that are grown in similar conditions (Lucas et al., 2015; French, 2016; Fogelfors, 2015; Lizarazo et al., 2015; Rölin, 2015; Heuzé et al., 2022). If the soil is more alkaline or has more clay, lupin will be less suited than for example faba beans (Jordbruksverket, 2004; Fogelfors, 2015; Lizarazo et al., 2015).

3.3.1 Agronomic management

The low nutrient requirements make lupin well suited for organic cultivation. No fertilization is needed as nitrogen will be fixated in the root nodules by *Rhizobium* bacteria and the deep roots will take up phosphorus (P) and potassium (K) further down in the soil profile (Lucas et al., 2015; French, 2016; Fogelfors, 2015; Heuzé et al., 2022). The amount of P and K that is removed with the harvest, about 3 kg and 8 kg per tonne of grain respectively, is better to replace by fertilizing a different crop in the rotation, as fertilization of lupin will have very little effect (French, 2016; Borgman, 2019). Field peas and faba beans are the most common grain legumes grown in Sweden, but with the risk of root rot when peas are grown too often, or chocolate spot disease and broad bean beetles becoming a bigger problem when growing faba beans, blue lupin can offer a break from field peas as well as cereals (Jordbruksverket, 2004; Fogelfors, 2015; Lizarazo et al., 2015; Gresta et al., 2017)

Sowing of lupin is preferably done early in the spring (French, 2016), around 1^{st} of April in Skåne, around mid-April by Västergöta plain, and around the end of April on the plains of Uppland (Andersson, 2020). Rain at the start of the summer is of great importance to get a good establishment (Borgman, 2019). It is also important to inoculate the seeds with the correct *Rhizobium* bacteria for the nitrogen fixation, which for lupin is *Bradyrhizobium lupini*, if lupin has not been grown on the intended field before (Lucas et al., 2015; French, 2016; Heuzé et al., 2022).

To achieve a more even maturation of the seeds on branched varieties, it is recommended to have the same plant density as for unbranched varieties (100-110 plants/m^2) as this prevents the lowest branches from setting seeds but without reducing the yield (Jordbruksverket, 2004; French, 2016).

Although lupin is drought tolerant, rain or irrigation will often lead to a higher yield as the survival of pods and seeds increase (Dracup et al., 1998).

Weed management

One of the biggest challenges with lupin cultivation is their inability to compete with weeds (Barker et al., 2016). On fields with a high weed pressure lupin should be grown together with a understory crop such as white clover to better compete against the weeds. If the field has a problem with perennial weeds, a different crop should be considered altogether (Jordbruksverket, 2004). Unbranched varieties of lupin are preferably grown together with oat or spring wheat as they mature at the same time and together keep the weed pressure down (Jordbruksverket, 2004). The weed issue is however not a problem for all growers, as with all crops it is possible to learn how to deal with it. With mechanical weeding consisting of two to three rounds of blind harrowing before emergence, and one to two rounds of weed harrowing after emergence, weeds are no longer mentioned as a problem for the more experienced growers (Andersson, 2020; Heuzé et al., 2022).

3.3.2 Nutritional qualities of the seeds

Figure 4. Blue lupin (Lupinus angustifolius L.) seeds of the variety Regent, dehulled to the left and hulled to the right.

The nutritional composition of lupin seeds is different from many other grains as they have a high protein content similar to that of soybeans, a high amount of dietary fiber (around 14% in dry matter) (Sujak et al., 2006), and nearly no starch (Petterson, 1998; Sweetingham & Kingwell, 2008; Lizarazo et al. 2015). The fat content in *L. angustifolius* is around 5-7% in dry matter (van Barneveld, 1999; Sujak et al., 2006), which is considerably less than soybean that has around 19% fat (Sinegovskaya et al., 2020). For *L. angustifolius* the protein content in dry matter ranges from 27% to 37% depending on the cultivar and growing condition (van Barneveld, 1999), which is lower than for *L. luteus* and *L. albus* which have 38-48% and 32-39%, respectively (Hickisch, 2020). Like many other legumes, lupin contains oligosaccharides that causes flatulence in humans (Han & Baik, 2006). This is due to a lack of the enzyme α-galactosidase that is needed to break down the oligosaccharides (Hickisch, 2020). The oligosaccharides are however easy to remove from the lupin flour, or at least reduce, through soaking, as the oligosaccharides are soluble in water (Han & Baik, 2006; Muranyi, 2017). As mentioned in the previous section, the alkaloids that make wild lupin inedible is not a problem in the cultivated varieties as the amount of alkaloids is less than 0.02% in 'sweet' lupin varieties. Dehulled lupin seeds (Figure 4), have a prominent yellow colour, due to carotenoids. Carotenoids have shown positive health effects when it comes to preventing certain chronic diseases (Wang et al., 2008).

3.3.3 Lupin for human consumption

In Sweden, lupin has recently been suggested as an alternative to soy both for food and feed for several reasons: i) lupin has a similar protein content to that of soy, ii) it is possible to produce lupin domestically as the climatic conditions in Sweden are more suitable to lupin than soy, soy for food and feed is currently imported from South America and other parts of Europe, iii) unlike soy, there are no commercial varieties of lupin that have been genetically modified, something that many consumers prefer, iv) lupin has a higher drought tolerance compared to soy, which is something to consider due to the ongoing climate change, v) the low nutrient requirements makes lupin a good option on nutritionally poor soils, vi) lupin is not affected by the same diseases as other legumes grown in Sweden, such as root rot on peas and chocolate spot disease on field beans (Wang et al., 2008; Bader et al., 2009; RISE, 2019; Hickisch, 2020; Karlsson, 2020).

During the past few years, several different companies throughout the food system in Sweden have been working together to try and establish new value chains for lupin and other legumes to support and encourage local producers to grow more of these crops (Borgman, 2019; RISE, 2019; Hushållningssällskapet, 2021). The collaboration showed promising results when using lupin for making pasta (RISE, 2019), but if the protein is extracted from the lupin seeds then a much wider range of products can made as lupin protein is an excellent emulsifier and foaming agent

(RISE, 2019; Ceresino et al., 2021). Companies like Lupinta and Nordisk Råvara are some of the first in Sweden to make use of the lupin grown in Skåne, where Lupinta make tempeh (boiled and fermented bean patties) and Nordisk Råvara supply whole seeds for food purposes. Products such as ice cream, yogurt and milk can be made vegan by using lupin protein (Fraunhofer, 2022).

Lupin protein is classified as an allergen with documented evidence of allergic reactions related to peanuts and other legumes (EFSA, 2006). Lupin protein as well as lupin flour used in food are also known for adding a green and bean-like flavour to the food, something that is not appreciated by consumers (Bader et al., 2009; Stephany et al., 2015; Stephany et al., 2016). The off flavour is linked to the activity of lipoxygenase (LOX), an endogenous enzyme in lupin that oxidizes mainly free fatty acids (Stephany et al., 2015). The milling and pH conditions when preparing the lupin flour and protein can greatly impact the activity of LOX, a low activity is preferred, which occurs in low temperatures and in a pH below 7 (Stephany et al., 2015). It is possible to inactivate LOX in whole lupin seeds through hydrothermal processes, where the seeds are in 100% humidity at 80°C for 7 minutes (Stephany et al., 2016).

4. Material and methods

4.1 Assessment of lupin cultivation in Sweden

A literature study was carried out to identify cultivation areas, drawbacks and benefits of lupin cultivation in Sweden. International databases such as Web of Science, Google Scholar and the SLU´s library search tool Primo were used to look for the following terms: "*Lupinus angustifolius*", "Sweden", "cultivation". The terms have been searched in English and Swedish. The results have been screened for information about location of cultivation, suitability, soil aspects, weed and pest control, cropping rotations, yield, and harvest management.

The findings of the literature assessment of lupin cultivation in Sweden were also complemented by an interview and correspondence exchange with Magnus Bengtsson from Körslätts Gård, a Swedish farmer that have grown blue lupin for more than 20 years in the south of Sweden.

4.2 Lupin processing into ice cream

A combination of two different patents (Snowden et al., 2007; Eisner et al., 2008) and the dissertation by Mittenmeier (2013) was used as references for extracting protein from the lupin seeds and to make ice cream from the protein extract. A Laboratory Mill 120 (Perten Instruments AB, Sweden) was used to mill the lupin seeds, a Sorvall Lynx 6000 Centrifuge (Thermo Scientific, AB Ninolab, Sweden) for centrifugation, and a Severin 2-in-1 Ice Cream Maker for making the ice cream. Food grade bicarbonate of soda and citric acid (Gert Strand AB, Sweden) was used to adjust the pH. The procedure for the protein extraction will not be shared in detail as the possibility of a new patent is being investigated. The general steps for the protein extraction were as follows:

1. The lupin seeds were milled into wholegrain flour.
2. Oligosaccharides and alkaloids were removed from the lupin flour by suspending it in water. The pH of the mixture was lowered to precipitate the protein. The mixture was then gently stirred at room temperature. A fine

cotton cloth was then used to separate the solids from the aqueous phase through filtration. The aqueous phase was centrifuged at 8000 g for 15 minutes after which the supernatant was removed, and the precipitate returned to the flour.

3. For the protein extraction, the wet flour was again suspended in water. The pH of the mixture was raised using bicarbonate of soda to make the proteins soluble. The mixture was then gently stirred at room temperature. A fine cotton cloth was then used to separate the solids from the aqueous phase with the proteins, through filtration. The filtration was done twice, the first time with one layer of cloth to remove the bulk amount of flour, the second time with two layers of cloth to remove finer fibre particles. The pH of the protein solution was lowered by using citric acid, this is to make the proteins insoluble again so that they can precipitate.
4. The proteins were then separated from the supernatant by centrifugation at 8000 g for 15 minutes, once the proteins had precipitated the supernatant was removed.
5. A small amount of the protein extract was dried to check the protein content. The rest of the protein extract was used for ice cream making.

Only Swedish, organic, and plant-based ingredients were used for the ice cream production. The lupin ice cream was prepared within the suggested proportions of ice cream ingredients according to Eisner et al. (2008):

3-4 % lupin protein
6-12 % fat (rapeseed oil)
5-25 % sugar
40-80 % water

The exact recipe for the lupin ice cream will not be published here as the possibility of a new patent is being investigated.

4.2.1 Sensory analysis

A sensory analysis for consumer acceptability (Sharif et al., 2017) was done on the 12th April 2022 at a conference room with a tasting panel of 19 participants that responded to a general invitation sent to different mailing lists within the Swedish University of Agricultural Sciences. The participants included students, researchers, technicians, and external visitors and are assumed to represent the typical population of consumers. Tables were organized in rows to ensure individual tasting areas with at least two meters separation between participants. Each participant was provided with a score card and a glass of water to rinse their palate between samples. The score card for the determination of taste and texture of the lupin ice cream had a 10-point hedonic scale (Hirschman & Holbrook, 1982) from 1 to 10, where 1 was not acceptable and 10 outstanding.

Before the beginning the tasting, participants were instructed to refrain from any kind of verbal communication during the three rounds of tasting to avoid interference in the perception of the ice cream from other participants. The tasting organizers explained the scoring systems before the beginning of the tasting and kept the verbal communication at minimal levels during the procedure, only informing about the flavour that would be served.

Three samples were served in sequence (raspberry, elderflower and strawberry) and participants had 7 minutes to taste the ice cream, with a 2-3 minute interval between samples. For each sample the participants noted down their scores for taste and texture together with an optional comment on their perceived experience.

Any comments were saved for potential future development of the products.

4.3 Economic performance of lupin cultivation and ice cream production

4.3.1 Economic performance of lupin cultivation

According to the actions taken in the lupin cultivation (provided by the interviewed farmer) and through literature studies, calculations were made to give an estimation of costs and revenues. Prices for agricultural operations, inputs and outputs concerning the lupin cultivation were obtained through public sources and from the interviewed farmer. The cost of seeds for sowing has been calculated by using 200 kg of seeds per hectare as used by Bengtsson[1] and by Nordisk Råvara AB for the project MegaLegumes[2], the price per kg of seeds were given by SkåneFrö AB[3] and was 17 SEK per kg. The cost of the work done on the fields include many different actions: Ploughing, rolling, sowing, rolling, blind harrowing in two rounds, weed harrowing in two rounds, harvesting, transport, drying and other logistics. For each action, the cost includes the cost of the driver, fuel, the tractor, equipment, wear and tear, insurance, and storage, as given by Bengtsson[4] for the year 2021 when doing contract work for other farms. Finding public farm gate prices for lupin harvests is not possible (HIR Malmöhus, 2011) as the small amount of lupin grown in Sweden is done so with individually priced contracts with buyers such as Nordisk Råvara (Dahlgren, 2021). So, in order to calculate the revenue from selling the crop, an assumption was made regarding the farm gate price for the harvest. Grains aimed

[1] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022
[2] Nordisk Råvara AB, pers. Communication via email. 15-03-2022
[3] SkåneFrö AB, pers. Communication via email. 15-03-2022
[4] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022

for human consumption generally get a higher price than grain for feed (Brink, 2022). The lupin seed harvest was here assumed to have the same farm gate price as organic field beans (5.35 SEK/kg (Brink, 2022)) because of the high protein content giving lupin a good commercial value (Wang et el., 2008), similar to that of field beans. A low lupin yield is according to Bengtsson[5] 1200kg/hectare, normal yield is usually around 2000kg/hectare, and a good yield around 3000kg/hectare, which goes in line with the yields mentioned by Jordbruksverket (2004).

4.3.2 Economic performance of lupin ice cream production

To calculate the cost of the lupin ice cream from a food business point of view, ingredient costs was sourced from established suppliers in Sweden, such as Martin & Servera, that supplies a large proportion of the food businesses in Sweden. Ingredient costs for restaurants are usually between 25-40% (Chatterjee, 2020), and 45-50% for food industries (Livsmedelsföretagen, 2022a), so a suitable share will be chosen according to these intervals and used to calculate the final price of the ice cream with 12% VAT added at the end. The cost of labour will not be included in the calculations as the protein extraction and the lupin ice cream production for this project are done on such a small scale that the cost of the labour would be unreasonably high in proportion to the amount of ice cream made. The ice cream machine used for this project can only produce 1.2 litres of ice cream per hour, which is a major limiting factor. General production costs within the food industry, such as labour, packaging, electricity, transports, etc., will be discussed.

4.3.3 Willingness to pay and market potential

During the sensory analysis of the lupin ice cream, the participants were also asked if they would buy the lupin ice cream and if so, what would be the maximum amount they would be willing to pay for it. In the absence of available market data, economist often use so-called stated preferences methods to understand consumer demand for goods and services. These methods can be broadly classified into contingent valuation studies (see e.g., Carson et al., 2001 for an overview on the debate in environmental economics) and discrete choice experiments (see e.g., Lizin et al., 2022 for a recent overview on studies and debates in food marketing). In my thesis, I have decided for a simple payment card contingent valuation format to keep the burden on the participants in the study low (see Rowe et al., 1996 for a discussion on the pros and cons). Participants were asked “Would you buy this product? Yes or No” and “If yes, what would be the maximum amount you would be willing to pay for a 500 ml tub of this vegan and organic ice cream that is sourced

[5] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022

and produced in Sweden?" To answer the second question the participants were given 13 different prices ranging from 29 SEK to 149 SEK. These questions were asked to identify an interest to buy the lupin ice cream as a finished product.
The results were then collected in a frequency distribution to see how the flavours differed from each other and how much each participant would be willing to pay.

The Swedish market potential for the lupin ice cream was investigated by comparing it to other similar products available on the Swedish ice cream market in terms of added product values and nutritional content.

Potential competitors were defined as having at least two of the following criteria: vegan, organic, produced in Sweden and/or using domestically produced ingredients. When the competitors had been defined it was noted in which criteria they would be competitors, and other aspects such as nutritional content and price were compared.

5. Results

5.1 Lupin cultivation in Sweden

Lupin can be grown as an alternative to field peas in boreal cropping systems as shown in a field trial in southern Finland (Lizarazo et al., 2014).

An example of an annual crop rotation with lupin given by Jordbruksverket (2004) can be seen in Table 2, with the addition of winter rapeseed (since the lupin ice cream has rapeseed oil in it), and another round of winter wheat to make use of the pre-crop effect of the rapeseed (Fogelfors, 2015). Magnus Bengtsson[6], an experienced organic lupin grower in the south of Sweden was interviewed for this project. The crop rotation at Bengtsson's farm can be seen in Table 2. There is a high proportion of legumes in this cropping system and the aim is to have an even distribution of the legumes in the rotation according to Bengtsson[7]. There is also a variation of this crop rotation with winter cereals and buckwheat grown on the farm.

Table 2. Two crop rotations including lupin. The left crop rotation shows an example from Jordbruksverket (2004) with the addition of winter rapeseed and winter wheat, the right one is the crop rotation currently used by the grower interviewed for this project.

Year	Jordbruksverket (2004)	Magnus Bengtsson[8], Körslätts Farm
1	Winter wheat	Lupin
2	Winter rapeseed	Spring cereal
3	Winter wheat + catch crop	White clover
4	Field beans + catch crop	Turnip rape
5	Barley with undersowing	Gray peas/oats
6	Green manure ley	Spring cereal
7	Potatoes/Sugar beets	Spring cereal
8	Lupin	

[6] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022
[7] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022
[8] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022

A normal yield for lupin seeds is around 2 tonnes per hectare in a boreal climate, but on a good year it can reach 3 tonnes or slightly more (Jensen et al., 2004; Jordbruksverket, 2004; Fraser et al., 2005; HIR Malmöhus, 2011; Lizarazo et al., 2015). Bengtsson[9] confirmed these numbers and mentioned that a low yield is around 1.2 tonnes per hectare. The average grain yield around the world in 2020 was just over 1 tonne while the Russian Federation showed an average of around 2 tonnes (Figure 5), which means that the Swedish grain yield for lupin is on the higher end in comparison to the world and similar to the Russian Federation.

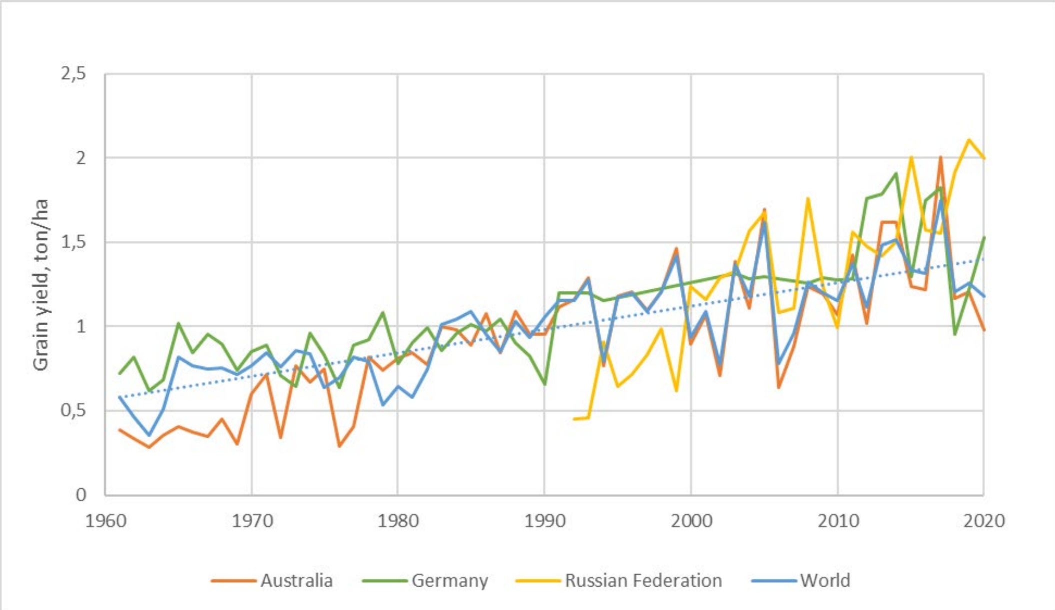

Figure 5. Average blue lupin grain yield in tonnes per hectare for Australia (The world's biggest producer of blue lupin grain), Germany, Russian Federation and the world. Data collected from FAOstat. The data from FAOstat show L. angustifolius, L. luteus and L. alba as a group, this should therefore be considered when looking at the data for the world. Australia, Germany and the Russian Federation mainly grow L. angustifolius and thus shows representative grain yield data for that crop (Gresta et al., 2017; Vishnyakova et al., 2021; Yagovenko et al., 2022)

Because most farmers in Sweden have not grown lupin previously, the inoculation is a must in most places (Gresta et al., 2017). The initial need of inoculation is mentioned by farmers as an extra cost and complicating factor by several lupin growers due to the time-consuming and manual labour involved when mixing the lupin seeds with the bacteria (Andersson, 2020).

[9] Magnus Bengtsson, Körslätts Gård, interview 14-03-2022

5.2 Lupin processing into ice cream

Three different lupin cultivars were used for the protein extractions and resulted in different proportions of extracted protein. For the first protein extraction. the variety Rumba was used and 29.4% (dry weight) was extracted as protein. For the second extraction the variety Mirabor was used and 26.7% (dry weight) was extracted as protein, Mirabor was however too bitter to use for the ice cream. For the third protein extraction, the variety Regent was used and 22.1% (dry weight) was extracted as protein, this batch was later used to produce lupin ice cream for a sensory analysis. The lupin beans were not defatted before extracting the protein and because the extraction method allows for some fat to precipitate with the protein extract there will be a small amount of fat in the protein extract (Eisner et al., 2008). The oil from the lupin beans has not been accounted for in the extraction of the protein, as it would require further testing of the protein extract to know exactly how much oil that was extracted together with the protein, something that was not possible for this study as time was limited. Lupin beans contain on average 6% oil (Stoddard, 2017), and not all of the oil would have been extracted as it depends on the pH conditions during the extraction (Eisner et al., 2008).

5.2.1 Sensory analysis

The three flavours (raspberry, elderflower and strawberry) with lupin ice cream were evaluated in a sensorial test. Overall, the three different flavours got very similar scores (Table 3), but when looking at the sum of all 19 scores the strawberry flavour did slightly better than the elderflower and the raspberry. All three flavours got a high proportion of score 7 or higher when it comes to taste (Figure 6). There were mixed opinions on the texture for all three flavours, as shown by the high variability in scores (Figure 7), reflected also on the lower sum on the texture scores compared to the sum of the flavour scores (Table 3).

Table 3. Results from the sensory analysis of the lupin ice cream. Taste and texture of the three different flavours were scored on a scale from 1-10 where 1 was not acceptable and 10 outstanding. The summary of all 19 scores for each flavour shows very small differences between the different flavours for both taste and texture.

	Taste				**Texture**			
Score	Min	Max	Median	Sum	Min	Max	Median	Sum
Raspberry	4	10	8	152	4	10	7	143
Elderflower	5	10	8	149	5	10	7	143
Strawberry	4	10	8	152	4	10	7	146

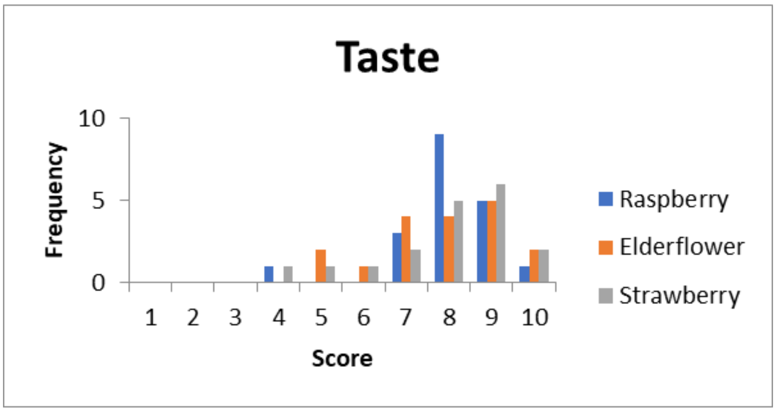

Figure 6. Frequency distribution of taste scores from the sensory analysis of the lupin ice cream. Taste of the three different flavours were scored on a scale from 1-10 by 19 participants where 1 was not acceptable and 10 outstanding.

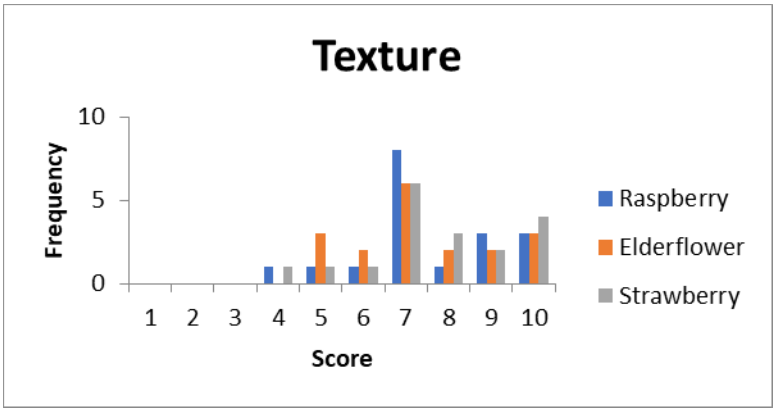

Figure 7. Frequency distribution of texture scores from the sensory analysis of the lupin ice cream. Taste of the three different flavours were scored on a scale from 1-10 by 19 participants where 1 was not acceptable and 10 outstanding.

5.3 Economic performance of lupin cultivation and ice cream production

5.3.1 Economic performance lupin cultivation

A rough estimation of the costs and benefits of growing lupin in an organic production with the resulting gross margin was carried out and is presented in Table 4, for details see section 4.3.1. The cost of seeds in this scenario is 3400 SEK excluding (ex.) VAT per hectare when applying 200kg/ha at a cost of 17SEK/kg. The total cost of the work on the fields adds up to 5350 SEK ex. VAT per hectare, slightly higher than the costs mentioned by HIR Malmöhus (2011) ten years ago, but with inflation added to the old numbers it ends up at the same price level (Ekonomifakta, 2022). Fertilization is not practiced and thus the cost for fertilizers has been added as 0 SEK. With 5.35 SEK/kg grain, a low, normal, and high yield will give a harvest revenue of 6,420 SEK, 10,700 SEK, and 16,050 SEK respectively, excluding VAT. For Bengtsson[2], lupin is one of his best crops in terms of revenue during years with a normal or high yield. The potential yield increase on winter wheat after growing lupin is 700kg/ha (HIR Malmöhus, 2011), and the farm gate price for organic bread wheat in 2021 was 3.19 SEK/kg grain (Brink, 2022), giving an extra benefit of 2,233 SEK/hectare. The gross margin for a year with a low yield ends up being just below break-even in this calculation, but with a normal or high yield, the gross margin shows a good result compared to other organic crops (Figure 8).

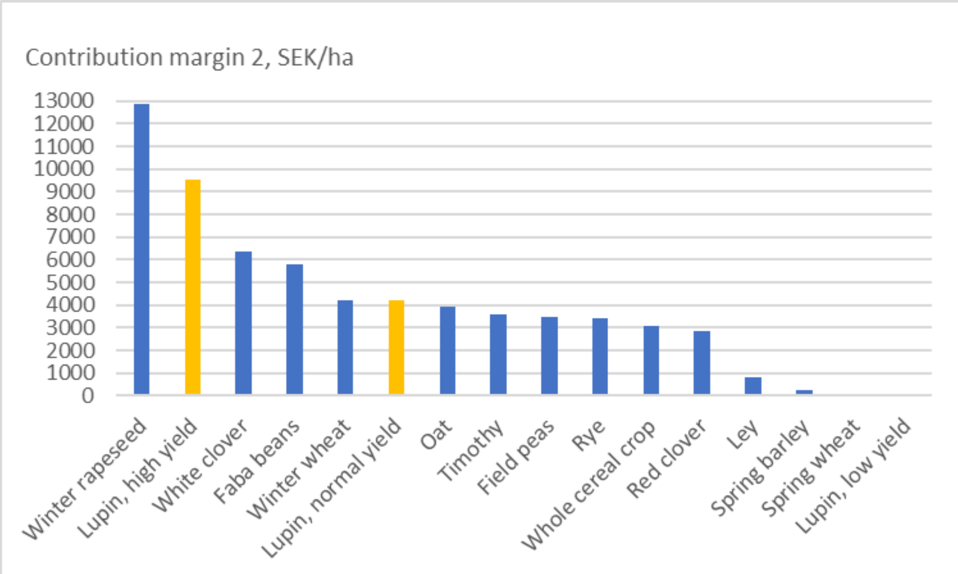

Figure 8. Contribution margin 2 (Revenue – variable costs – fixed costs) in SEK/ha for common crops grown by organic farmers in 2015 in comparison with the calculated gross margin, Table 4, for low, normal and high grain yield of lupin marked in yellow. Figure adjusted from Hushållningssällskapet (2017).

Table 4. An estimation of costs, revenues, and gross margins in SEK per hectare excluding VAT, when growing organic lupin. Low, normal, and high yield has been calculated with 1200kg/ha, 2000kg/ha, and 3000kg/ha respectively. Cost of seeds was 17 SEK/kg as given by SkåneFrö AB in 2022 multiplied by the sowing rate of 200kg/ha as practiced by Magnus Bengtsson. Fertilization is not practiced and is therefore added as 0 SEK. The cost of work on the fields was given by Magnus Bengtsson. Positive impact on WW calculated with 700kg/ha yield increase (HIR Malmöhus, 2011) multiplied with a farm gate price of 3.19 SEK/kg (Brink, 2022). WW= winter wheat

	Low yield	Normal yield	High yield
Cost of seeds	-3400	-3400	-3400
Work on the field + logistics	-5350	-5350	-5350
Fertilizer	0	0	0
Harvest revenue	6420	10700	16050
Positive impact on WW after	2233	2233	2233
Gross margin:	-97	4183	9533

Magnus Bengtsson has a close cooperation with Nordisk Råvara where they together have invested in machinery for cleaning and dehulling lupin seeds from his own cultivation and from other local lupin producers, giving Bengtsson a more even workload throughout the year and some extra revenue (Dahlgren, 2021). Nordisk Råvara aim to give their growers a reasonable income with individually priced contracts for the grain harvest, the retail price of the grain is then adjusted accordingly (Dahlgren, 2021).

5.3.2 Economic performance of lupin ice cream production

The ingredients cost of producing the protein extract has been calculated by using the amount of lupin flour, citric acid and bicarbonate of soda needed to produce 1 unit of protein extract. Organic raspberries and strawberries were sourced from a local producer in Örsundsbro, and because of the high price on Swedish, organic, hand-picked berries, this was also the biggest ingredient cost (Table 5). Organic and Swedish rapeseed oil, sugar and potato starch was sourced from Martin & Servera. The cost of the elderflower cordial used for the elderflower flavour, was based on the price given by one of the major supermarket chains in Sweden. The total ingredient cost was highest for the raspberry flavoured lupin ice cream and lowest for the elderflower flavoured lupin ice cream (Table 5). A small overrun was measured for the lupin ice cream as it weighed 96g per 100ml, this was taken into consideration when calculating the retail price. The resulting retail sales price based on cost of the ingredients (Table 5) shows that the lupin ice cream would be at the very top of the price range for premium ice cream compared to other ice cream alternatives on the market (Table 6).

Table 5. Ingredient cost and suggested retail sales price for 500ml of organic and vegan lupin ice cream, sourced and produced in Sweden. All prices in SEK.

	Raspberry	**Strawberry**	**Elderflower**
Ingredient cost (ex VAT)	37	31	17
Ingredient proportion of sales price	40%	40%	30%
Retail sales price (inc. VAT)	103	87	64

Willingness to pay

The result from the two questions about the consumers' willingness to pay show that the majority of the participants at the sensory analysis would buy the lupin ice cream and would be willing to pay from 39 SEK to 139 SEK (Figure 9). Out of those who said "Yes" to buy the raspberry lupin ice cream, 41% would be willing to pay 79-109 SEK. Of those willing to buy the elderflower lupin ice cream, 53%

would be willing to pay 69-139 SEK. For the strawberry lupin ice cream, the price range was the same as for the raspberry flavour but 53% would be willing to pay that price instead of 41%. Overall, the highest frequencies for the willingness to pay are seen in the range between 59 SEK and 89 SEK.

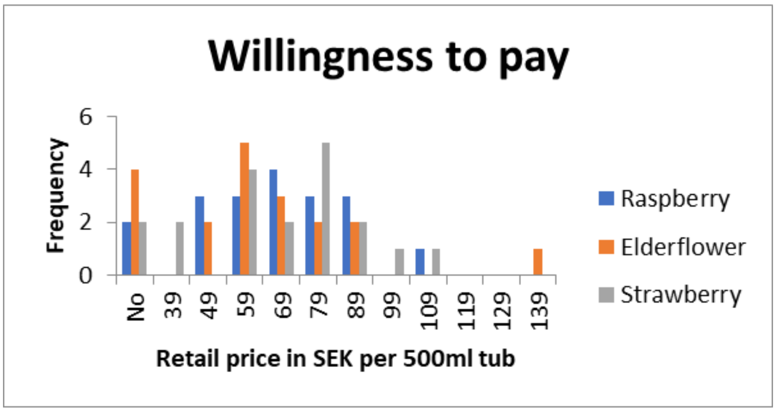

Figure 9. Question asked during the tasting of the lupin ice cream to see if the participants would buy the product and if so, how much they would be willing to pay for it. The results show that the majority of the participants would buy the lupin ice cream and how much people are prepared to pay for a 500ml tub ranges from 39 SEK to 139 SEK.

Market potential

Swedes are eating more ice cream than ever, and sales have increased more than the volume, which indicates that premium ice cream is gaining market shares (Nordevik, 2022). When comparing the three different lupin ice creams to competitors on the market, the lupin ice cream stands out from the crowd in terms of both nutrition and the added qualities that they present (Table 6). The lupin ice cream is the only one that is 100% vegan, organic, sourced in Sweden and produced in Sweden, most of the other competitors can only match two of those qualities. In terms of nutrition, the lupin ice cream shows a low sugar and fat content together with one of the higher protein contents, and because the fat in the lupin ice cream comes from rapeseed oil, the amount of saturated fat is very low. Lagerqvist (2019) investigated the social-, financial- and environmental sustainability of ice cream sold in Sweden and found similar results, that most of the ice cream available have two of the sustainability aspects but not the complete set. The lupin ice cream would be socially and financially sustainable as the nutritional profile offers a healthier alternative and promotes local producers, and it would be environmentally sustainable in the sense that it is vegan and has local organic ingredients that have not travelled long distances. This could potentially appeal to a wider range of consumers that would normally have to choose which sustainability aspect they value the most.

Table 6. A comparison of potential competitors on the ice cream market and the lupin ice cream produced in this project. The criteria to be part of this list was that the ice cream should have at least two of these qualities: Vegan, organic, produced in Sweden. The lupin ice cream stands out from the crowd in a positive way both when it comes to meeting the criteria and nutritionally. None of the competitors used only Swedish ingredients, six of the options had Swedish main ingredients. Note that the fat content for the lupin ice cream does not include potential fat present from the lupin seeds, lupin seeds contain up to 6% fat that can be extracted together with the protein depending on the pH during extraction.

Brand	Flavour	Vegan	Organic	Swedish ingredients	Produced in Sweden	Price, lowest	Price, highest	Protein	Sugar	Fat	of which is Saturated fat
Järna glass	Vanilla	No	Yes	Only milk	Yes	59,95	63,95	2,61%	22,50%	11,00%	3,66%
Järna glass	Salted caramel	No	Yes	Only milk	Yes	54,95	59,95	3,70%	15,80%	16,00%	14,20%
Järna glass	Chocolate	No	Yes	Only milk	Yes	59,95	61,95	3,74%	19,70%	11,00%	3,85%
Järna glass	Blueberry	No	Yes	Only milk	Yes	59,95	61,95	3,90%	21,00%	14,00%	9,00%
Lily & Hannas	Cookies & caramel	Yes	Yes	No	No	69,95	77,95	2,30%	18,20%	19,00%	12,70%
Lily & Hannas	Strawberry & cheesecake	Yes	Yes	No	No	69	74,95	3,50%	28,80%	11,20%	5,00%
Lily & Hannas	Caramel vanilla	Yes	Yes	No	No	69	69	2,30%	20,90%	18,10%	12,90%
Lily & Hannas	Chocolate	Yes	Yes	No	No	69,95	74,95	2,60%	21,40%	13,80%	8,50%
Gute glass	Honung & saffran	No	Yes	No	Yes	65,95	65,95	4,00%	19,30%	14,20%	8,00%
Gute glass	Strawberry lime	Honey	Yes	No	Yes	65,95	65,95	0,20%	30,10%	0,10%	0,00%
Gute glass	Raspberry peppermint	No	Yes	No	Yes	65,95	65,95	3,40%	21,70%	11,60%	6,50%
Gute glass	Chocolate	No	Yes	No	Yes	65,95	65,95	4,80%	19,30%	14,50%	8,20%
Lejonet & Björnen	Raspberry sorbet	Yes	No	No	Yes	59,95	59,95	0,20%	29,00%	0,10%	0,00%
Lejonet & Björnen	Mocca	No	Yes	No	Yes	62,95	62,95	4,90%	26,00%	13,00%	8,20%
Lejonet & Björnen	Vanilla	No	Yes	No	Yes	55,95	62,95	5,00%	26,00%	13,00%	8,20%
Sia Glass	Raspberry sorbet	Yes	No	No	Yes	22,95	22,95	0,20%	31,00%	0,10%	0,00%
Sia Glass	Cloudberry	No	Yes	Only milk and egg	Yes	33,9	40,5	2,70%	24,00%	14,00%	9,20%
Sia Glass	Vanilla	No	Yes	Only milk and egg	Yes	33,9	44,95	3,00%	21,00%	16,00%	10,00%
Oatly	Chocolate	Yes	No	No	Yes	39,95	39,95	1,20%	25,00%	11,00%	5,80%
Oatly	Salted caramel	Yes	No	No	Yes	39,95	39,95	0,80%	23,00%	12,00%	6,10%
Djurgårds Glace	Vanilla	Yes	No	No	Yes	58,95	58,95	0,00%	14,00%	16,00%	6,00%
LUPIN	Raspberry	Yes	Yes	Yes	Yes			4,00%	10,96%	10,00%	0,70%
LUPIN	Strawberry	Yes	Yes	Yes	Yes			4,00%	11,98%	10,00%	0,70%
LUPIN	Elderflower	Yes	Yes	Yes	Yes			4,00%	14,10%	10,00%	0,70%

6. Discussion

6.1 Cultivation

Finding information on lupin grown in Sweden is difficult because of the novelty of this crop, most of the information originates from a small set of sources that to some extent refer to each other. The interest in lupin has however increased a lot in the last few years as it offers a local alternative to soy (Andersson, 2020), so as more and more farms start to grow lupin this information gap should decrease.

The crop rotation (Table 2) from Jordbruksverket (2004) is aimed for the most southern part of Sweden where lupin and sugar beets can be grown according to climate and suitable logistics. From 2022, there will be only one facility processing sugar beets to produce sugar in Sweden, which is in Örtofta in Skåne (Abdi Onsäter, 2021), hence this crop rotation only works in Skåne from a logistical point of view. Sugar beets are also known to cause soil compaction due to the extremely heavy load of the harvest collected in trailers (Götze et al., 2016), the lupin is therefore extra important in the crop rotation to restore some of the soil structure. There is also faba beans in the crop rotation from Jordbruksverket (2004) which should realistically be swapped for field peas since faba beans and lupin grow on different type of soils (Lizarazo et al., 2015). To use lupin as a break crop in annual cereal dominated crop rotations (as in the second crop rotation mentioned in Table 2) could be a suitable option for farms in other parts of the country as well. When lupin is used as an alternative to peas it will help to lower the pressure of root rot and it will also fix a larger quantity of nitrogen compared to peas (Baddeley et al., 2013), which will benefit the subsequent crop (Jensen et al., 2004).

Many of the drawbacks with growing lupin are connected to the start-up phase, such as the cost of seeds and inoculation (Jouan et al., 2019), weed competition and finding buyers for the harvest (Watson et al., 2017). These drawbacks will become less important over time as the inoculation is only needed initially (Gresta et al., 2017). The cost of seeds can be reduced considerably on the second season already by saving seeds from the previous harvest, something that the few Swedish lupin producers are practicing (Andersson, 2020). Due to the very small amount of lupin grown in Sweden, the selection of different cultivars from Swedish seed suppliers is in most cases limited to three options: Regent, Mirabor and Boregine, a broader selection would be preferred by many growers and can be found abroad (Andersson, 2020). Once lupin has become a more common crop on Swedish fields, seed companies will most likely be able to offer more varieties because they then have a market to sell it to, and food industries can develop when there is a larger supply of lupin seeds from the farms. The different parts of this food value chain will have to work together to be able to grow (Watson et al., 2017), something that has been recognised by MegaLegumes (Borgman, 2019), and LoBa (Hushållningssällskapet, 2021), two collaborations that involve growers, chefs, retailers and other actors in the food value chain.

When growing lupin for human consumption, having a good yield is however of no use unless there are buyers that are willing to buy the produce. More food value chains involving lupin are needed in Sweden to overcome this very important bottleneck that prevents more farmers from growing lupin (Lucas et al., 2015; Watson et al., 2017; Borgman, 2019).

6.2 Processing

The protein extracted from the lupin seeds showed a very positive emulsifying quality when used to make vegan ice cream corroborating the findings of Mittermaier (2013) and Muranyi (2017), something that could also be useful for other food products (Sweetingham & Kingwell, 2008). There is however a great need for companies in Sweden that are able to do the extraction in order to keep the production domestically, especially if the protein is to be used on a bigger scale.

When the protein is extracted from the seeds, a large quantity of water is needed to first remove oligosaccharides and alkaloids, and secondly to solubilize the proteins. So on a larger scale, the water usage would have to be optimized as much as possible to not use excessive amounts of water that could affect the local water supply (Klemeš & Perry, 2007). The supernatant removed during the protein extraction could possibly be used for irrigation if the production site is close to a plantation; the need for filtration of the wastewater should then be investigated (Klemeš & Perry, 2007). Another by-product from the protein extraction is the pulp, meaning the flour left after the protein extraction. The pulp is a large proportion (around 70% of dry matter) of the seed (Sujak et al., 2006) that under current circumstances is not being used. After going through the protein extraction, the pulp has a larger volume and weight as it has soaked up large quantities of water, something to consider when looking at further usage of the pulp. More research is needed regarding what the pulp can be used for, but a suggestion would be to make a different version of the traditional yellow pea soup that many people in Sweden eat on a regular basis, or falafel. Even after the protein extraction, there is still a small amount of protein left in the pulp to benefit from, as the extraction is not

100% effective (Mittermaier, 2013). Using the pulp from the protein extraction for human consumption might take some time to sort out, so in the meantime the pulp could be used as feed for farm animals (Watson et al., 2017).

During the sensory analysis, some of the participants commented on a slight bitterness or aftertaste that most likely comes from the lupin protein for two reasons: i) the protein used for that particular batch did not go through a pre-extraction to remove the bitterness as it takes a quite sensitive palate to be able to taste it, ii) a green or bean-like flavour can be present (Bader et al., 2009) if there was a high LOX activity during the protein extraction (Stephany et al., 2015). The LOX activity peaks at pH 7.5 which is very close to the pH where the protein is solubilized, a high LOX activity is therefore likely since no attempt was made to inactivate LOX before extracting the protein. To inactivate LOX the seeds should have gone through a hydrothermal process (Stephany et al., 2016) as mentioned in section 3.3.3. This shows the importance of the pre-extractions and LOX inactivation, since some people are still able to taste some off flavours.

The potato starch used as a thickener gave a good result in terms of keeping the ice cream from having a water-like texture when it melts, but it also made the ice cream slightly grainy, which was not optimal. For future batches, the potato starch could be excluded and replaced by Maltodextrine as suggested by Eisner et al. (2008). This would however compromise the aspect of keeping all ingredients Swedish, as the raw material used to produce Maltodextrine (waxy corn) is mainly cultivated in Northern Italy for the European market (Bortolini & Martello, 2013). It is also possible to increase the amount of sugar in the lupin ice to get a creamier texture (Goff & Hartel, 2013).

6.3 Financials

The financial calculations for this project have been particularly difficult because of the few data points available to make calculations from and the broad view on the food value chain did not allow enough time to find more data. Even with more data, the cultivation part of the financial calculations is dependent on the specific situation for each farm as most depend on individual contracts (Jouan et al., 2019), so a one-for-all calculation is not possible. The gross margins calculated for low, normal and high yield of lupin seeds (Table 4) can therefore be seen as one particular but realistic situation. When growing lupin and other grain legumes, it is important to take into consideration the effect that it can have on the cropping system, which can be more than the outcome as a single crop. Grain legumes can increase the harvest of the subsequent cereal crop with on average 29% when grown with a low nitrogen input (Cernay et al., 2018), the lower need for fertilization will also reduce costs (Reckling et al., 2016; Jouan et al., 2019). The grain yield of lupin can vary a great deal from season to season, with a low yield being around 1.4 ton/ha (Fraser et al., 2005) and a high yield around 3.7-4.1 ton/ha (Jensen et al., 2004; Lizarazo et al., 2015). This variability is a risk that many farmers are not willing to take (Jouan et al., 2019), but when a high grain yield is sold for the purpose of human consumption (e.g. lupin ice cream) the gross margin can in some situations be better than growing cereals (Reckling et al., 2016).

Food industries in Finland spend 59% of their costs on raw material, 17% on labour, 16% on other production costs such as packaging, energy and transport, 4% on hired services, and 3% on capital costs (Mattsson & Perälä, 2017). In Sweden, the cost of labour is high compared to many other countries (Ekonomifakta, 2022), and due to the war in Ukraine and the COVID-19 pandemic, the cost of raw material has increased to record levels and thus considerably taken down the profitability for many food industries in Sweden (Livsmedelsföretagen, 2022a;b). Having the proportion of raw material low in terms of costs as assumed for the lupin ice cream, gives a bit more room for the cost of labour, energy and transport to withstand potential chocks from the market like the events just mentioned.

For the lupin ice cream, the cost of ingredients is high due to the premium combination of Swedish and organic ingredients and the retail price end up being higher than that of the potential competitors. The lupin seeds bought from Nordisk Råvara[10] can be purchased in bulk giving it a lower price. However, it was not possible to calculate the cost with the lower price for this small laboratory production. The retail price for the lupin ice cream could be reduced further by adding more overrun (meaning more air is worked into the ice cream to give it a lighter texture), this would reduce the weight over volume (Goff & Hartel, 2013) and therefore reduce the cost of the ingredients per tub.

Reducing the retail price for the lupin ice cream to a level more equal to other premium ice creams would be preferable, especially for the raspberry flavour, as around 100 SEK per 500 ml tub most likely will exceed the consumers' willingness to pay when other premium ice creams cost 60-80 SEK per 500 ml. This reduction would most likely mean that one of the aspects (organic, vegan, Swedish production) chosen for this project would have to be compromised.

[10] Nordisk Råvara AB, pers. Communication via email. 15-03-2022

7. Conclusions

Blue lupin is suitable to be cultivated in the southern half of Sweden because of a long enough season for maturation of the seeds. It is preferably grown as an alternative to field peas as the growing conditions are similar, it should also be placed in a position where it can provide the most benefits to the crop rotation as a whole because of the low need for fertilization and the positive effect for the subsequent crop. Blue lupin is valuable as a break crop from both cereals and other legumes as it does not suffer from the same diseases and pests, the high protein content also makes blue lupin a good alternative to soy for both food and feed.

The drawbacks with growing lupin are mostly connected to the start-up phase because of the high cost of seeds, the labour intense inoculation needed when sowing on virgin fields, and learning how to deal with the weed competition since blue lupin is a weak competitor. There is also a need for collaboration between farmers and other parts of the food value chain in order to grow the market around lupin and to secure the supply and demand of lupin seeds.

A vegan and organic ice cream made from 100% Swedish ingredients was successfully produced by extracting protein from lupin seeds and using it as a base for the vegan ice cream, showing that it is viable to use lupin for that purpose from a technical point of view. There is however a great need for companies in Sweden that can extract protein from the lupin seeds on larger scale, and more research is needed regarding the high water usage and what the remaining part of the lupin flour can be used for once the protein has been extracted.

Financially, blue lupin has the potential to be one of the better crops grown in Sweden in terms of gross margins, as long as the yield is normal or higher. Once the cultivation is more established, there is a potential for increased margins as well, depending on how the grower chooses to manage the cultivation. When producing a vegan organic ice cream from Swedish ingredients, the resulting product will have a premium retail price. No other ice cream was found on the Swedish market with the full combination of added values that the lupin ice cream offers, and this together with a healthier nutritional profile shows that the lupin ice cream would fill a gap on the market.

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Popular science summary

Sweden imports large quantities of soy to use as feed for farm animals and food for human consumption because of the high protein content, but what happens when imports are disrupted? The COVID-19 pandemic and the war in Ukraine has shown the importance of food security, as food imports cannot always be guaranteed. The way forward for many countries is to promote local farmers to produce food in order to reduce the need for imported food. Global food systems are unsustainable in many more ways than just the dependency on imports, where what we choose to eat is the main factor that affects nearly all other factors. It is possible to feed 10 billion people in a sustainable way on the agricultural land already available, by choosing to eat more plant-based food. The amount of land needed to produce plant-based food is significantly less than for meat and dairy, which is why plant-based protein, is so important if meat and dairy intake is to be reduced.

Blue lupin has been suggested as an alternative to soy in Sweden because of the similar protein content and because it, unlike soy, is possible to grow successfully in Swedish conditions. Blue lupin (*Lupinus angustifolius*) is a cultivated species of lupin, not to be confused with the wild growing garden lupin (*Lupinus polyphyllus*), which is poisonous and commonly seen along roadsides in Sweden. In Australia and Poland, lupin is a common crop that has been grown for many years, but in Sweden this is a new crop that very few farmers have grown before.

The aim of this project was to look at the possibilities around growing lupin in Sweden for the purpose of making a vegan ice cream based on lupin protein and only organic Swedish ingredients. The project has a broad view on the food value chain around the lupin ice cream where many different aspects are considered, such as benefits and drawbacks of lupin cultivation, the processing of lupin beans for extracting protein and making ice cream, as well as to see if the cultivation and processing holds up financially.

The results show that blue lupin is healthy crop that offers a valuable break from cereals and other legumes such as field beans and peas. This is because lupin is not affected by the same pests and diseases as the other crops. There is no need to fertilize lupin as the deep roots take up nutrients deep down in the soil and like all legumes, it can fixate atmospheric nitrogen with the help of bacteria in root nodules. Lupin can also increase the harvest of the next crop, because the deep roots improve the soil structure and the nitrogen fixation is high enough that some is left in the soil for the next crop. Learning how to handle a new crop can however take time and is seen as a drawback for lupin. The initial cost of the seeds is high and the bacteria needed for the nitrogen fixation has to be added to the seeds when lupin is grown for the first time on a field, a disadvantage compared to other crops. This can however improve already on the second season if seeds are saved from the first harvest, and once lupin is grown regularly on a field the need to add nitrogen fixating bacteria to the seeds is less crucial. With a normal to high grain yield, lupin has the potential of being one of the better crops in Sweden in terms of farm income, when it is grown under organic management and for human consumption (grain for food generally gives a higher income than grain for feed).

Protein was successfully extracted from lupin seeds in this project and then used as a base for vegan ice cream. Three different ice cream flavours (raspberry, strawberry and elderflower) were produced using only organic Swedish ingredients, and a tasting panel gave both taste and texture good scores for all three flavours. The premium combination of Swedish organic ingredients resulted in a high retail price, so high that consumers would have to pay a fair bit more for the lupin ice cream compared to other premium ice creams. Further development is needed to reduce costs, but there is still a good potential for the lupin ice cream on the market as it is perhaps the only ice cream that is both vegan and organic as well as sourced and produced in Sweden. More research is also needed on what to do with the rest of the lupin seed, after the protein has been extracted, as this is the majority of the seed.

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