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Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden

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Abstract

The Western diet is characterized by high meat consumption, which negatively affects the environment and human health. Transitioning toward eating more plant-based products in Western societies has been identified as a key instrument to tackle these problems. However, one potential concern is that radically reducing meat in the current diet might lead to deficiencies in nutritional intake. In this paper, we explore a scenario in which meat consumption in Sweden is reduced by 50% and replaced by domestically grown grain legumes. We quantify and discuss the implications for nutritional intake on population level, consequences for agricultural production systems and environmental performance. The reduction in meat consumption is assumed to come primarily from a decrease in imported meat. We use data representing current Swedish conditions including the Swedish dietary survey, the Swedish food composition database, Statistics Sweden and existing life cycle assessments for different food items. At population level, average daily intake of energy and most macro- and micro-nutrients would be maintained within the Nordic Nutrition Recommendations after the proposed transition (e.g., for protein, fat, zinc, vitamin B12 and total iron). The transition would also provide a considerable increase in dietary fiber and some increase in folate intake, which are currently below the recommended levels. The transition scenario would increase total area of grain legume cultivation from 2.2% (current level) to 3.2% of Swedish arable land and is considered technically feasible. The climate impact of the average Swedish diet would be reduced by 20% and the land use requirement by 23%. There would be a net surplus of approximately 21,500 ha that could be used for bioenergy production, crop production for export, nature conservation, etc. Implementation of this scenario faces challenges, such as lack of suitable varieties for varying conditions, lack of processing facilities to supply functional legume-based ingredients to food industries and low consumer awareness about the benefits of eating grain legumes. In sum, joint efforts from multiple actors are needed to stimulate a decrease in meat consumption and to increase cultivation and use of domestically grown grain legumes.

Introduction

It is becoming increasingly clear that to sustainably supply food to a growing population, improvements only on the production side (through increases in productivity, improved management and use of technology) will not be sufficient (Bajželj *et al.*, 2014). A transition toward less resource-demanding diets in Western societies, that is, diets containing less animal products and more plant-based foods, has been identified as one of the most efficient mitigation options to reduce environmental pressures from the food system (Röös *et al.*, 2017) and to curb demand (Bijl *et al.*, 2017). For people who currently have a high intake of red meat, reducing meat consumption would also have clear health benefits (Wolk, 2017).

However, a drastic reduction in animal-based products in current Western diets can introduce new health challenges. White and Hall (2017) investigated the radical scenario of removing all livestock from US agriculture and replacing feed production on cropland with increases in food crops proportional to currently grown crops, resulting mainly in an increase in cereals and grain legumes. They found that food production in total would increase by 23%, but that domestic supplies of calcium, fatty acids and vitamins A and B12 would not be sufficient to meet the requirements of the US population. Millward and Garnett (2010) also mention the risk of nutrient deficiency in a transition to diets with fewer animal products, highlighting especially zinc, calcium, iodine, vitamin B12 and riboflavin, and also protein supply for the

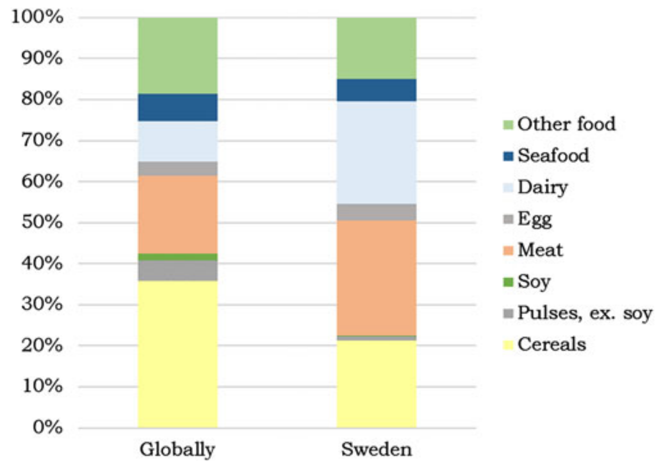

Fig. 1. Contribution of different sources to protein supply globally and in Sweden in 2013 (FAO, 2017*b*).

elderly. Hence, when promoting more plant-based foods in diets, these nutritional risks have to be carefully monitored and handled. We suggest that legumes can play a key role in addressing these challenges.

Legumes belong to the plant family Fabaceae, which contains a vast diversity of plants. These include crops grown for seed (e.g., dry beans, dry peas and lentils), fresh vegetables (e.g., green beans and green peas) and livestock forage (e.g., clover and alfalfa). In addition to their high value in human and animal nutrition, legumes provide important agronomic benefits, including symbiotic nitrogen (N) fixation and by serving as break crops in cereal-based cropping systems. The term *grain legumes* refers to legumes grown for their edible seeds, harvested mature and dried before sale. The term grain legumes is often used synonymously with pulses, but according to the definition used by FAO (FAO, 2017*a*), pulses exclude grain legumes mainly used for extraction of oil, for example, soybean.

Grain legumes are an important source of protein in developing countries, but in developed countries, animal-source protein now dominates (Joshi and Rao, 2017). On a global level, grain legumes (excluding soybean) made up 5% of the protein supplied to human diets in 2013 (FAO, 2017*b*). This is similar to the proportion of protein supplied by fish and seafood (6%), but considerably less than the contribution from cereals (36%) and meat (19%) (Fig. 1). In Sweden, the protein contribution from grain legumes, cereals and meat is 1, 21 and 28%, respectively (FAO, 2017*b*) (Fig. 1). Consumption of grain legumes is thus exceptionally low in the Swedish diet, while meat (and milk) intake is far above the global average. Meat consumption has also increased continuously for a number of years. Since 1960, per capita meat consumption in Sweden has increased by 73% (SS, 2017*a*). Current daily per capita consumption of legumes in Sweden is 12 g, but eating patterns differ considerably between individuals and only 50% of Swedish women and 44% of Swedish men include legumes in their diet (NFA, 2012). Hence, despite the health and environmental benefits of grain legumes, the trend globally is now toward more animal protein in all countries in which income is rising (Rivers Cole and McCoskey, 2013). Thus, a revival in grain legumes as an important food crop is needed, as this could provide a solution to several food system challenges.

The overarching aim of this multidisciplinary paper is to explore the role of grain legumes in the necessary transition to more healthy, resource-efficient and environment-friendly human food systems. We use the case of Sweden and explore, for a range of different aspects, a scenario in which meat consumption is reduced by 50% and replaced by domestically grown grain legumes. We quantify and discuss the implications of such a transition in terms of nutritional intake on population level, for agricultural production and environmental performance. Finally, we discuss challenges in implementing this scenario, focusing on consumer acceptance and production aspects.

The grain legumes considered are faba beans (*Vicia faba*), yellow peas (*Pisum sativum*), gray peas (*P. sativum* var *arvense*), common beans (*Phaseolus vulgaris*) and lentils (*Lens culinaris*). These grain legumes are currently grown to various extents in Sweden, and there are possibilities to enlarge their cultivation if market demand increases. Although we look at Sweden as a specific case, this analysis is also highly relevant for other countries or regions with similar production and consumption patterns.

Background

Health benefits of grain legumes

Grain legumes are a good source of protein, carbohydrates, minerals and vitamins (Table A1). The nutrient content is largely dependent on legume type, species, cultivar and growing conditions. The protein content of legumes is up to threefold higher than in cereals. Moreover, legumes contain high amounts of the amino acid lysine, which is low in cereals, and therefore legume protein favorably complement cereal protein. In contrast to meat and meat products, legumes are also rich in dietary fiber, unsaturated fatty acids and the essential nutrient folate, dietary intake of which is below the recommended level in the Nordic countries. With the exception of soybeans, grain legumes are usually low in fat (≈1%) and free from saturated fatty acids and cholesterol (Table 1). According to the Swedish food composition database (NFA, 2017), one serving of cooked legumes (140–190 g) provides <300 calories and provides a significant amount of daily recommended nutrients: up to 50% of the folate requirement, up to 85% of dietary fiber and up to 15% of protein and potassium.

On the other hand, legumes contain a number of bioactives that are traditionally classified as anti-nutritional compounds, which may reduce the bioavailability of nutrients. However, their adverse effects are currently being re-evaluated, as emerging research has shown that several of these compounds may also have beneficial effects on health (Table A2). In addition, most treatments such as soaking and cooking reduce the content of anti-nutritional compounds (Table A3).

There is strong scientific evidence of the positive effects of legumes on health (Table 2). Legumes have a low glycemic index, attributable to their high content of dietary fiber and resistant starch compared with other starchy foods, which is of interest in prevention of disease, for example, cardiovascular disease and type 2 diabetes (Messina, 2014; Clemente and Olias, 2017).

Acknowledgement of the health potential of grain legumes is reflected in numerous eating guidelines such as the revised Australian Dietary Guidelines, where tofu and sprouted legumes are listed as health-promoting foods for the first time [reviewed by Kouris-Blazos and Belski (2016)]. In the recent US Dietary Guidelines (USDA, 2017), legumes are listed as vegetables for a healthy diet. Legumes are also promoted in the Swedish dietary advice (NFA, 2015).

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Table 1. Nutrient content in cooked portions of grain legumes compared with meat products

	Serving size (g)	Energy (kcal)	Protein (g)	Fat (g)	Total dietary fiber (g)	Iron (mg)	Potassium (mg)	Folate (µg)
Grain legumes, cooked with salt								
White beans	190	205	15	1.1	13	5.1	789	154
Brown beans	190	260	17	1.7	25	4.1	555	112
Faba beans	170	187	13	0.7	9	2.6	456	177[a]
Gray peas	170	221	17	0.9	15	3.4	493	7
Yellow peas	140	145	10	0.5	5	2.7	352	9.1
Green lentils	150	191	14	1.1	14	4.8	540	60
Meat products								
Beef chuck, boiled	100	184	26	8.8	0	3.3	224	4
Chicken breast fillet, fried	100	134	27	2.5	0	0.3	361	20
Pork collar or chaps, fried	100	202	21	13	0	1.8	268	7
Liver patties, fried	100	146	13	6.4	0	9.6	385	114

Adapted from the Swedish food composition database (NFA, 2017) and [a](USDA, 2017).

Table 2. Beneficial health effects of legumes

Health outcome	Effect	
Glycemic control, metabolic syndrome and type-2 diabetes	Replacing carbohydrate-rich foods with legumes reduces postprandial glucose elevation in both diabetic and non-diabetic subjects. Regular legume consumption reduces the risk factors for metabolic syndrome.	Strong evidence
Cardiovascular diseases	Epidemiological studies show that regular consumption of legume-rich foods has a cardio-protective effect by decreasing risk factors (hypercholesterolemia and hyperlipidemia).	Strong evidence
Hypertension	The high content of potassium and magnesium in legumes improves blood pressure management.	Strong evidence
Gut health	Research suggests that legumes provide dietary fiber, resistant starch and oligosaccharides, which have a key role in modulating gut microbiota by increasing beneficial bacteria and associated beneficial metabolites.	Insufficient data
Body weight and satiety	It is suggested that legumes increase satiety and thereby reduce food intake, resulting in weight loss.	Insufficient data
Cancer	It is suggested that regular intake of legumes reduces the risk of various types of cancer, e.g., colorectal, prostate and stomach cancer, because of increased intake of isoflavones and dietary fiber.	Inconsistent

Summarized from: Clemente and Olias (2017), Messina (1999), Messina (2014), Polak *et al.* (2015), Rebello *et al.* (2014) and Sánchez-Chino *et al.* (2015).

Benefits for cropping systems

Thanks to the ability of legumes to form root nodule symbioses with N_2-fixing bacteria, legumes add substantial inputs of N to cropping systems worldwide and reduce the need to produce energy-demanding synthetic N fertilizers (Jensen *et al.*, 2012; Voisin *et al.*, 2014). Symbiotic N_2 fixation not only provides the legume crop with N, but also supplies the following crop with part of its N requirement. International reviews report considerably higher yields and amounts of residual plant-available soil N for cereals grown after legumes compared with cereal crops (Preissel *et al.*, 2015; Stagnari *et al.*, 2017). Field experiments and farm surveys have shown that N fertilization rates for cereals after grain legumes can be reduced by 20–35 kg N per hectare (ha) without affecting yield levels, compared with cereals after cereals (Preissel *et al.*, 2015; SBA, 2016). Based on field trials performed in Sweden, the Swedish Board of Agriculture (SBA, 2016) estimates a yield increase corresponding to 0.5–1 metric tonne (hereafter ton) per ha in cereals grown after grain legumes compared with cereals following cereals. This expected yield increase can be compared with the results from a meta-analysis of European cropping systems by Preissel *et al.* (2015), who found large variations in the yield advantage of grain legume pre-crops depending on fertilizer strategy and reference pre-crop. Average yield increase of grain legume pre-crops compared with cereal pre-crops was 2.2 tons ha^{-1} in unfertilized cereal crops and 0.7–1.5 tons ha^{-1} in moderately and highly fertilized cereal crops in that European meta-analysis (Preissel *et al.*, 2015).

Legumes also serve as break crops, exploiting the benefits of a diversified crop rotation in cereal-dominated crop production systems. The break crop benefits include reduced problems with crop diseases and weeds (Kirkegaard *et al.*, 2008; Stagnari *et al.*, 2017; Watson *et al.*, 2017), improved soil structure/increased content of soil organic matter (West and Post, 2002; Hernanz *et al.*, 2009; Preissel *et al.*, 2015) and increased availablity of other plant

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nutrients such as phosphorus (Shen *et al.*, 2011). According to Ebert (2014), the current overwhelming dominance of a few major crops (wheat, rice, maize) in global agriculture poses a high risk of crop failure. In this context, diversification of cropping systems by increased legume cultivation could increase the resilience to stress caused by variable weather conditions or weeds, insect pests and diseases (Ebert, 2014). Another advantage of integrating legumes into cropping systems is that they enrich the landscape with flower resources that are often scarce in cereal-dominated cropping systems, thereby enhancing the diversity and abundance of bumblebees and other insects that can provide ecosystem services, for example, pollination, for other crops (Köpke and Nemecek, 2010). Further benefits of legumes include potential for enhanced soil C sequestration, building soil fertility (Jensen *et al.*, 2012).

Considering their environmental benefits and potential for enhanced economic profitability through savings on inputs (reduced need for fertilizers and pesticides) and yield increases in subsequent cereal crops, grain legumes are strongly underused crops in European agriculture. Currently, <2% of the agricultural land in Europe is used for the cultivation of grain legumes (Watson *et al.*, 2017). Due to the risk of increasing problems with soil-borne diseases, pathogens and pests, grain legumes cannot be grown too frequently on the same land (Watson *et al.*, 2017). However, among the diversity of grain legume species and varieties, it should be possible to identify grain legume crops that can be grown in most European pedo-climatic regions. Thus, even with careful restrictions regarding the frequency of grain legumes in crop rotations, there is room for considerable increases in the area of grain legume cultivation in Europe.

Benefits for the environmental impact of food systems

Legumes, most importantly soybeans, are a feed ingredient in many livestock diets. However, when human-edible biomass is fed to animals, this entails an unavoidable loss of calories and nutrients available to humans. Mottet *et al.* (2017) found that, on a global scale, 2.8 kg of human-edible feed is used to produce 1 kg of ruminant meat, while for monogastric species (pigs and poultry) the corresponding value is 3.2 kg. Hence, with few exceptions, animal-based foods show larger negative environmental impacts than plant-based foods (Di Paola *et al.*, 2017) (Fig. 2).

A review of life cycle assessment (LCA) studies on food has shown that the cradle-to-farm gate climate impact of dried and fresh legumes, that is, the aggregated and weighted emissions of different greenhouse gases (GHG) arising on the farm and from the production of inputs, varies between 0.15 and 2.46 kg of carbon dioxide equivalents (CO_2e) per kg of legume (Clune *et al.*, 2017). The major sources of on-farm GHG emissions from legume cultivation are nitrous oxide (N_2O) emissions from soils and carbon dioxide (CO_2) emissions from fossil energy use in field machinery and irrigation equipment. As production and use of N mineral fertilizer is associated with considerable GHG emissions, legumes can contribute to mitigation of climate change by allowing mineral fertilizer to be replaced with N_2 fixation (Jensen *et al.*, 2012). Existing LCA studies on specific legumes do not fully consider the beneficial effects that legumes bring to other crops and the crop rotation by the pre-crop effects which reduce the need for mineral fertilizers and pesticides ('Benefits for cropping systems' section). Therefore, the benefits of legumes compared with other protein sources are probably underestimated in such studies.

The nitrogen footprint, the total direct N losses to the environment that occur for the production of 1 kg of food, is also higher for animal-based than plant-based foods, due to N losses from manure management and the need for greater cropland areas for feed production. Leip *et al.* (2013) modeled the N footprint of different foods in the European Union (EU) and found that legumes had about half the N footprint of milk, 10% of that of pork and only 2% of that of beef, but still had a higher N footprint than fruit, vegetables and potatoes. However, legumes had the lowest 'nitrogen investment factor' (quantity of new reactive N required to produce one unit of N in the product) of all foods, only 1–2 kg of N per kg of N in legumes compared with 15–20 kg N per kg of N in beef. As for emissions of ammonia, these are considerable from livestock production due to emissions from manure management (Röös *et al.*, 2013).

Another important environmental impact category related to food production is pesticide use, leading to toxic effects on ecosystems and humans. Data availability on these aspects is very limited, but Nordborg *et al.* (2017) found that the potential freshwater ecotoxicity impact of bread, milk, minced beef, chicken fillet and minced pork was approximately 2, 3, 50, 140 and 170 times that of pea soup, respectively. Moreover, in comparison with Brazilian soybean, all Swedish crops scored significantly better, due to more rigorous legislation, agronomic practices with comparatively more diverse crop rotations and climate conditions preventing certain disease and pest problems. This illustrates that pesticide use, and hence the ecotoxicity impact, of growing legumes is highly variable and highly dependent on the type of cropping system and that there are good possibilities to implement practices for grain legume production with low overall ecotoxic impact.

In addition, the ecotoxic impact from increasing cultivation of grain legumes is affected by the use of pesticides not only in the actual crop itself, but also in following crops. Several studies report lower ecotoxicity impacts when grain legumes are included in cereal-dominated crop rotations (Nemecek *et al.*, 2008; MacWilliam *et al.*, 2014). Increasing crop diversity by avoiding grain legume monocultures or heavily legume-dominated cropping systems, and promoting non-chemical measures to control weeds, pests and diseases, will thus be key for reducing ecotoxicity impacts and reaping the other benefits from introducing grain legumes into cereal-dominated cropping systems. In this perspective, organic agriculture provides one example of a method for cultivating grain legumes with low or no chemical inputs, especially since the yield difference between organically and conventionally grown grain legumes is relatively small (de Ponti *et al.*, 2012).

Material and methods

Description of the meat reduction scenario

To analyze the prospects and challenges of reducing meat consumption in favor of legumes, we selected the case of Sweden and an explorative scenario in which meat consumption is reduced by 50%. There were four reasons for this level of reduction. First, it would keep consumption by high-meat consumers well below the level recommended by the World Cancer Research Fund (max. 500 g of cooked red meat per week) to reduce the risk of some cancer forms, which is also the maximum red meat consumption level stated in dietary advice from the Swedish National Food Agency (NFA, 2015). Secondly, it is the

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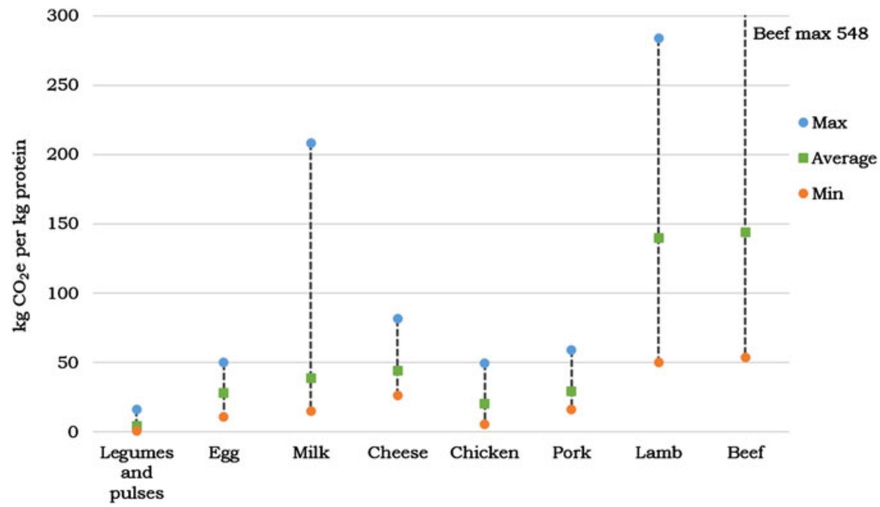

Fig. 2. Climate impact of legumes and pulses per kg protein relative to animal-based protein sources. Based on data from Clune *et al.* (2017).

level of reduction advocated by WWF Sweden for several environmental reasons[1]. Thirdly, it would reduce Swedish meat consumption to approximately the global average (from 84 to 42 kg carcass weight per capita per year; FAO, 2017*b*), in line with an international contraction and convergence strategy in which the current global meat consumption is distributed equally across global citizens as suggested by McMichael *et al.* (2007). Fourth, although even deeper cuts in meat consumption would probably be needed to reach global environmental targets (Bajželj *et al.*, 2014), a 50% reduction as a first step would be in line with some emissions pathways to limit global warming to 2°C as stipulated by the Paris agreement (Hedenus *et al.*, 2014).

In our scenario, we assumed an equal reduction in meat across the main livestock species and across different animal parts (muscles and offal). We took data on meat consumption from the latest national food consumption survey Riksmaten (NFA, 2012), which reports an average daily per capita intake of meat products of 110 g, divided among different products as follows: red meat 63 g, chicken 22 g, sausage 21 g, offal 3 g and blood 1 g (NFA, 2012). Hence, a 50% reduction means a reduction in meat products of 55 g. In our scenario, this meat is replaced by 55 g of cooked grain legumes daily, corresponding to approximately 20 g dried legumes. After accounting for total postharvest losses of 11% (FAO 2011), the amount of grain legumes required for the transition scenario corresponds to an annual total of 75,000 tons for the Swedish population (10 million people). Replacement based on edible weight rather than energy or protein content is justified because the energy and protein content in the Swedish diet on a population level is well within the recommended range (NFA, 2012), so it is not necessary on a population level to replace all energy and protein provided by meat. Moreover, we assumed that, when shopping for foods, consumers base their purchase decisions on the amount of food, rather than the energy and protein content.

Assumptions on grain legume cultivation

Crop production in Sweden, as in many other developed countries, is characterized by a high degree of specialization. The plain areas of central Sweden are dominated by cereal production, while perennial grass, often in combination with clover, for dairy and beef production is mainly found in less favorable agricultural areas with mixed farmland and woodland (SS, 2017*c*). In 2016, perennial grass or grass/clover was the most frequently cultivated crop, grown on 40% of the total cropland in Sweden, followed by wheat (17%) and barley (13%). Approximately 70% of Swedish cropland is currently used for feed production (SS, 2017*c*).

Grain legumes are only grown on 2.2% of the total cropland area in Sweden (SS, 2017*c*) and production is dominated by two crops: faba bean (104,000 tons from 30,000 ha) and yellow (dry) pea (93,000 tons from 25,000 ha) (SS, 2017*b*). The majority of Swedish faba bean and yellow pea production is currently used as animal feed. Sweden also produces approximately 1000 tons common bean, mainly the brown bean variety which was grown on about 600 ha in 2016 (SS, 2017*b*). Since common bean is frost sensitive and requires a long growing season and dry weather during autumn, production has so far been restricted to suitable soils in south-east Sweden, mainly the island of Öland on the Swedish east coast (Fogelberg, 2008). Due to consumer demand, there is increasing interest within the food industry in extending Swedish common bean production, which has increased in area lately (expanding to land previously not used for common bean, e.g., on the island of Gotland[2]) and diversity (adding, e.g., black, borlotti, kidney and white bean varieties) in recent years[3]. Until recently, fresh pea was grown on 9000–10,000 ha in Sweden, but this dropped to 2500 ha in 2017 (SS, 2017*b*) as a consequence of changes in contract production by the main Swedish fresh pea-producing company.

Based on the above, the additional legume consumption in the transition scenario was assumed to consist of 40% each of faba beans and yellow peas, 10% gray peas, 8% common beans and 2% lentils. This mixture was chosen to provide variation in the types of legumes consumed, while taking into account the feasibility of increasing Swedish cultivation of different legume species and varieties. For example, it would have been beneficial for nutrient intake to further increase the proportion of common beans

[1]http://www.wwf.se/wwfs-arbete/klimat/earth-hour/tema-biffen/1550488-earth-hour-budskap-biffen

[2]'Increased cultivation of beans and lentils', news article on Swedish Radio, https://sverigesradio.se/sida/artikel.aspx?programid=94&artikel=6724639 (retrieved on 23 April 2018).

[3]See, for example, 'Bean trend can increase the interest in legume cultivation', news article in Swedish agricultural newspaper Land Lantbruk http://www.landlantbruk.se/lantbruk/bontrend-kan-oka-intresset-for-baljodling/ (retrieved on 23 November 2017).

and lentils, but the Swedish cultivation area for these crops is restricted by climate and infrastructure (on-farm machinery, experience/skills in cultivation techniques, transportation to cleaning and processing facilities). Further increase in the production of common beans and lentils can be considered feasible in the long term.

We assumed that the legumes needed for replacing the meat are domestically grown. We based this assumption on political and consumer interest in more regional foods and more local food systems. In addition, the Swedish Food Strategy (GOS, 2016) ratified in 2016, aims at increasing Swedish food production, another reason why considering domestic supply is relevant. For the same reason, we assumed that the reduction in meat consumption comes primarily from a decrease in imported meat. Approximately 50% of beef consumed is currently imported to Sweden (SBA, 2017*c*), so our assumed 50% reduction in beef does not affect domestic beef meat production. For pork and chicken, approximately 30% is imported (SBA, 2017*a*, 2017*b*), so the scenario involves a decrease in Swedish pork and chicken production of 40,000 tons bone-free pork and 25,000 tons bone-free chicken (29%).

To produce 1 kg of bone-free pork in Sweden, 5.6 kg of cereals are used, while to produce 1 kg of bone-free chicken, 2.5 kg of cereals are used (Cederberg *et al.*, 2009). As most cereals used for feed in Sweden are domestically grown, a 29% reduction in domestic pork and chicken production would 'free up' 288,000 tons of cereals, corresponding to approximately 48,000 ha of cropland. The reduction in domestic meat production would also mean a reduction in the use of domestically grown rapeseed, faba bean and pea as feed for pigs and poultry. According to Cederberg *et al.* (2009), 0.06 kg of domestically grown rapeseed and 0.08 kg faba beans and peas are used for producing 1 kg of bone-free pork, while the corresponding figures for producing 1 kg of bone-free chicken are 0.03 kg of domestically grown rapeseed and 0.13 kg faba beans and peas. Hence, in total, 3600 tons of rapeseed are 'freed up' when domestic pork and chicken production is reduced in the transition scenario, which corresponds to approximately 1000 ha. Finally, in total, 8400 tons of legumes are 'freed up' when domestic pork and chicken production is reduced. This amount was subtracted from the total requirement for faba beans and peas in the calculations for the transition scenario. Even though quality requirements are often higher when crops are used as food ingredients rather than when used as animal feed, this difference was assumed to be negligible in this context. The other feedstuffs used for pigs and poultry are either imported or are by-products from the food industry. Hence, its decreased used in the scenario does not affect Swedish agriculture.

Calculation of nutrient intake

In the current Swedish diet, meat and meat products are the main source of protein, zinc, vitamin B12 and iron, providing about 20–30% of the total daily intake of these nutrients. An important question is therefore how well the proposed scenario of reducing meat consumption by 50% and replacing it with legumes based on mass, complies with current Nordic Nutrition Recommendations (NNR) (Norden, 2014) on population level.

To investigate this, we compared the current intake of nutrients, based on data from the recent Swedish dietary survey (NFA, 2012) (not accounting for under- or overestimation of consumption of certain foods), to outcomes from the transition. For simulating the scenario after transition, the average nutrient contribution from meat and meat products was cut by 50% and replaced by the nutrient contribution of a daily portion of 55 g cooked grain legumes (see 'Description of the meat reduction scenario' section) using data from the Swedish food composition database (NFA, 2017). The recommended daily intake was based on the reference adult (average for men and women aged 30–64 yr, with body weight 70 kg, a sedentary lifestyle, and a low physical activity level of 1.4). We also looked at the folate and total iron relative to NNR specifically for women of reproductive age, as recommendations for women (400 μg for child-bearing age and 500 μg during pregnancy and lactation) are much higher than the recommended level (300 μg) for the general population.

Calculation of environmental impacts

We estimated how the climate impact and land use of the average Swedish diet would change in our transition scenario by halving the GHG emissions and land use from meat reported by Röös *et al.* (2015) and adding emissions and land use from production and preparation of the additional grain legumes. Röös *et al.* (2015) assessed the climate impact and land use from the current Swedish diet to be 1.9 tons CO_2e and 0.34 ha per capita per year, respectively. This was done by multiplying values on food consumption from the recent Swedish dietary survey (NFA, 2012) by LCA values on climate impact and land use for foods on the Swedish market. Regarding post-farm processing of the grain legumes, we accounted for emissions caused by cooking yellow peas based on Röös *et al.* (2015), which are of the same magnitude as emissions from preparation and freezing of processed pea burgers according to Davis *et al.* (2010) (approximately 0.25 kg CO_2e per kg of grain legumes, compared with emissions caused by growing the legumes of 0.7 kg CO_2e per kg of legumes).

Based on current average mineral N fertilization rates of 103 kg N per ha to cereals and 143 kg N to oilseed rape (SS, 2017*d*), we calculated the reduced need for mineral N fertilizer in the transition scenario as a consequence of reduced use of cereals and rapeseed for animal feed. We also estimated the effect on domestic ammonia emissions, using emission factors for different animal products from Vallin *et al.* (2016).

If the increased grain legume cultivation is based on mixed cropping systems, reducing the need for pesticides compared with monocropping, it is likely that water pollution in the form of pesticide residues and excess nutrients from fields will also be reduced in the scenario. However, the exact extent of this reduction is difficult to establish due to the uncertainty in terms of what will happen with the 'surplus' cropland, and therefore a quantitative estimate of total water pollution was not included in this study. However, we calculated the change in N load to recipient waters from Swedish wastewater treatment systems due to the lower N content in the diet in the transition scenario. We based this assessment on figures from Vallin *et al.* (2016) on the average N removal efficiency of municipal sewage systems and on-site systems and the number of people connected to these systems.

Results and discussion

Impacts on nutrient intake

As shown in Figure 3, after the proposed transition, the estimated average daily intake for energy, fat, protein, vitamin B12, zinc and

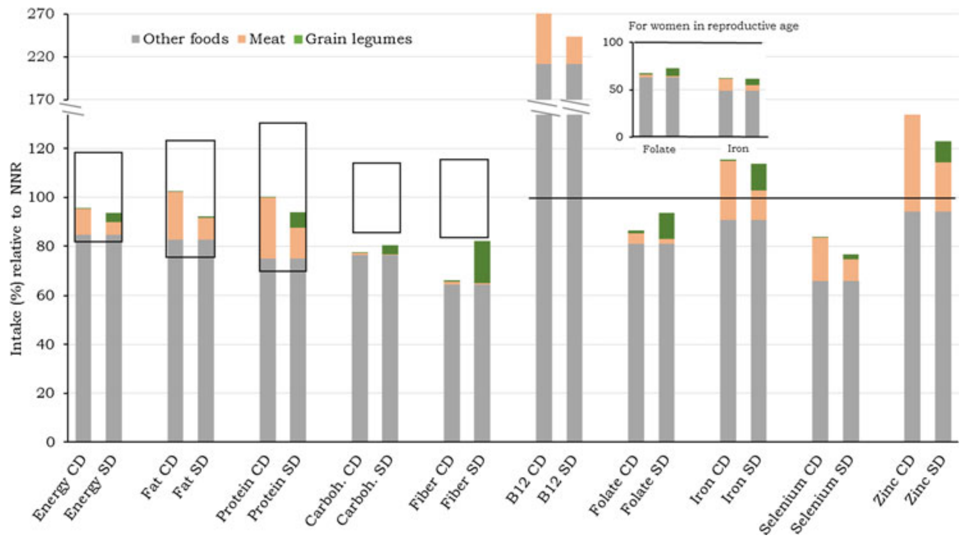

Fig. 3. Intake (%) of key nutrients in the current Swedish diet (CD) and in the scenario diet (SD) in which meat is reduced by 50% and replaced with legumes, relative to the Nordic Nutrition Recommendations (NNR) (Norden, 2014). The recommended daily intake is based on the reference adult (average for men and women aged 30–64 yr, with body weight 70 kg, a sedentary lifestyle and a low physical activity level of 1.4), shown as the range (boxes) for energy, fiber and macronutrients. The black line represents the recommended average daily micronutrient intake for men and women (for folate and iron the recommendation for the reference adult is given, please note that this is below the recommendation for women of reproductive age) (Norden, 2014). The insert shows intake of folate and total iron relative to NNR for women of reproductive age.

total iron is still within the recommended range, even before adding the grain legumes to the diet. (No data are shown for the other vitamins and minerals that are above recommendations in both scenarios.) However, calculations for iron based on the average requirements for men and post-menopausal women mask the fact that, for women of childbearing age and during pregnancy, the diet does not meet the dietary recommendations either before or after the transition (Fig. 3). Irrespective of the dietary regime chosen, women of childbearing age are recommended to consume more total iron and especially the more bioavailable heme iron. The same applies to pregnant women, who are recommended by NNR to take a supplement of 40 mg as a general dose or 60 mg as an individual prophylactic to ensure normal iron status. The situation is similar for selenium, for which average intake is lower than recommended in the current diet due to low selenium content in Swedish soils, and intake is further decreased in the scenario diet.

The estimated energy intake remains almost unchanged after the transition and the intake of carbohydrates is slightly increased (Fig. 3). While there is a trend for a reduction (~10%) in total fat intake (Fig. A1), the nutritional quality is improved by the higher content of health-beneficial unsaturated fatty acids.

The most beneficial aspect increasing the legume consumption is the increased intake of fiber and folate. The current average fiber intake in the Swedish population is far below the recommended level (Fig. 3), amounting to 20 g day^{-1}. In the transition scenario, the fiber intake increases by 25% through incorporation of grain legumes (Fig. A1), to 25 g day^{-1}, which is at the lower limit of the recommendation. Average folate intake is also improved after the transition, due to the incorporation of grain legumes. This is of particular importance for women of childbearing age and during pregnancy and lactation.

To summarize, dietary changes according to the scenario with reduced meat and increased legume consumption – provided consumers maintain a varied diet – would not negatively affect nutrient intake on population level. However, for some individuals, especially those with a low intake of meat, those with specific nutritional requirements or pregnant women, reduced meat consumption is not recommended without introducing measures to ensure that intake of critical micronutrients is met by careful selection of specific foods in the diet or by supplementation, as only voluntary fortification is practiced in Sweden. It should also be borne in mind that the choice of meat and meat products can have an impact on the nutritional quality; for example, it is recommended to reduce intake of processed meat products rather than fresh meat.

Impact on and challenges for agricultural production

The transition scenario would require about 26,500 ha for the increased Swedish cultivation of grain legumes (Table 3), which is approximately 1% of Swedish arable land. Since the amount of land that would be made available due to the reduction in domestic chicken and pork production (reduced need for cereals and rapeseed in animal feed) exceeds this value, there is enough agricultural land in Sweden to enable the transition. Compared with the current land use, there would be a net surplus of about 21,500 ha that could be used for other purposes, such as cultivation of bioenergy crops or food crops for export, or for nature conservation.

However, even though more than enough cropland is made available in the transition scenario by reduced cereal and rapeseed cultivation (less animal feed), expanding grain legume cultivation to the required level might be challenging, at least for some crops. The area of increased faba bean and yellow pea cultivation in the transition scenario (8900 ha each) corresponds to approximately 33% of the current cultivation of these two crops. Assuming that the current faba bean and pea production is maintained after the transition (i.e., in addition to the amounts required for the transition), the total cultivation of these crops would then amount to approximately 73,000 ha. This is still only about half the area that could potentially be used for these two grain legumes in Sweden, according to an analysis of the potential for domestic production of protein crops (Gustafsson *et al.*, 2013).

On the other hand, it might be more difficult to increase the production of gray pea, common bean and lentil to meet the amounts required in the transition scenario. Gray pea and lentil can be cultivated and harvested with standard machinery on farms that produce cereals, and these two crops are well suited for the climate and common soil types in southern and central Sweden. However, both crops are prone to lodging, and weed management is a major challenge in lentil cultivation (Döring, 2015). Intercropping with a

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Table 3. Assumed yield levels and required area for each of the legume varieties assumed in the transition scenario

Crop	Amount needed (t)	Yield (t ha^{-1})	Requirement for replacement (ha)[a]
Faba bean	30,100	2.9	8900
Yellow pea	30,100	2.9	8900
Gray pea	7500	2.5	3000
Common bean	6000	1.7	3500
Lentil	1500	0.7	2100

Yields of faba bean, yellow pea and common bean correspond to national averages for these crops during the period 2000–2016 (calculated from annual reports from Statistics Sweden). Yields of gray pea and lentil are estimates based on unpublished results from field experiments in Skåne, southern Sweden, as statistics for these crops are missing.
[a]For faba bean and yellow pea, the amount of 8400 t that would be freed up by reduced need for animal feed was subtracted from the total amount needed (4200 t each) before calculating the land area requirement.

cereal crop is known to reduce both the risk of lodging and the abundance of weeds (Hauggaard-Nielsen *et al*., 2008; Döring, 2015), but large-scale application of intercropping will require multi-actor collaborations to generate knowledge about cultivation techniques and facilitate sorting of the mixed crops (Bedoussac *et al*., 2015). Scaling up Swedish gray pea and lentil cultivation from the currently very low level is therefore associated with important challenges, at least in the short term.

Concerning common bean, its share in the transition scenario would require production to be more than four times larger than today. This increase would require expansion outside the regions where common bean is currently produced in Sweden, and since efficient harvesting of common bean requires special combine harvesters (Fogelberg, 2008), this expansion involves challenges such as investment in machinery and acquisition of knowledge for cultivation of a new crop. The suitable cultivation area for common bean is restricted to south-east Sweden, due to the crop's sensitivity to frost and the need for dry weather during harvest. The amount of common beans required in the transition scenario might therefore be close to the maximum potential production of the crop within Sweden.

The transition scenario could have included additional grain legumes, for example, narrow-leaved lupin (*Lupinus angustifolius*) and soybean (*Glycine max*). Lupin could be of particular interest, since it can potentially be grown on soils that are less suitable for common bean, faba bean or pea. Due to their limited current use in Swedish agriculture (lupin and soybean) and the lack of available data on nutritional content (lupin), these crops were not included in the calculations for the transition scenario. However, this choice does not exclude the possibility that lupin and soybean can play important roles for future Swedish cultivation and use of grain legumes.

Assuming that current Swedish grain legume cultivation remains unchanged, the additional 26,500 ha in the transition scenario would increase the total grain legume area to 3.2% of Swedish arable land, compared with the current level of 2.2%. While this is an important increase in relative terms (45%), 3.2% is a small proportion of total cropland and there is still potential for further increasing grain legume cultivation for both feed and food, allowing more farmers to exploit the benefits of grain legumes in their cropping systems.

On a general level, challenges that need to be overcome to reach the production levels required in the scenario include: legume yield variability (lack of adapted varieties, difficulties in controlling weeds, pests and diseases), low awareness about rotational benefits (yield improvements and cost savings in subsequent crops) and tradition (generally low interest in grain legumes among researchers, advisors, plant breeders, seed producers and traders) (Zander *et al*., 2016; Watson *et al*., 2017). For example, increased investments in grain legume breeding to develop varieties that mature earlier or are more cold-tolerant would make it possible to expand grain legume production into areas with no or low current production, for example, in northern Sweden. Enhanced cropping systems research and advisory capacity could also be promoted to improve the generation and exchange of knowledge for optimizing the benefits of grain legumes in crop rotations (Magrini *et al*., 2016; Zander *et al*., 2016). Regarding yield variability, weed control can partly be achieved by mechanical means and the integration of weed-suppressive cover crops, complementing and reducing the use of herbicides. Furthermore, intercropping grain legumes with cereals is known to significantly reduce weed problems, and has also been shown to reduce certain diseases and pests (Hauggaard-Nielsen *et al*., 2008).

Research shows that increasing farmers' awareness of the benefits of legume growing will not be sufficient to reach the goal of agriculture system transition to achieve wider benefits. To increase the adoption rate, aspects of profitability and other non-profit-related factors also need to be addressed (Kuehne *et al*., 2017). Environmental and risk aspects are important. Support from agricultural development agencies is needed to foster adoption of more legume-based farming practices and to compensate for losses when animal production is reduced. However, policies to support this transition will have to consider the complex interactions between agricultural systems, market demand and the climate impact from farming, processing and consumption (Wigboldus *et al*., 2016).

Impact on the environment

The per capita climate impact and land use related to food consumption would be reduced by 20 and 23%, to 1.5 tons CO_2e and 0.26 ha, respectively, by a 50% reduction in meat consumption and addition of 55 g cooked grain legumes per day (Fig. 4a and b). A 20% reduction in the climate impact of food consumption is a considerable decrease. An additional 20–30% is likely to be achievable through improvements on the production side. Bryngelsson *et al*. (2016) quantified this potential under 'moderate' and 'optimistic' assumptions for Swedish food consumption, including strategies such as low-emitting manure handling, the use of renewable energy and increased livestock efficiencies. They found the mitigation potential from such improvements to be between −31% ('moderate' assumptions) and −57% ('optimistic' assumptions) of the emissions caused by the current Swedish diet. The Swedish Board of Agriculture presents a more modest estimate, that the GHG emissions from Swedish agriculture could be reduced by approximately 20% through improvements in management and new technologies (SBA, 2012). Together with the decrease from halving meat consumption investigated in this study, this could reduce the climate impact of the Swedish food system by approximately half or potentially more. This can be compared with the Swedish targets for reductions of GHG, which state that emissions should be reduced by 63% by 2030 and by 75% by 2040 (compared with 1990) from sectors not covered by the EU Emissions Trading System, including agriculture (The Swedish Parliament, 2017).

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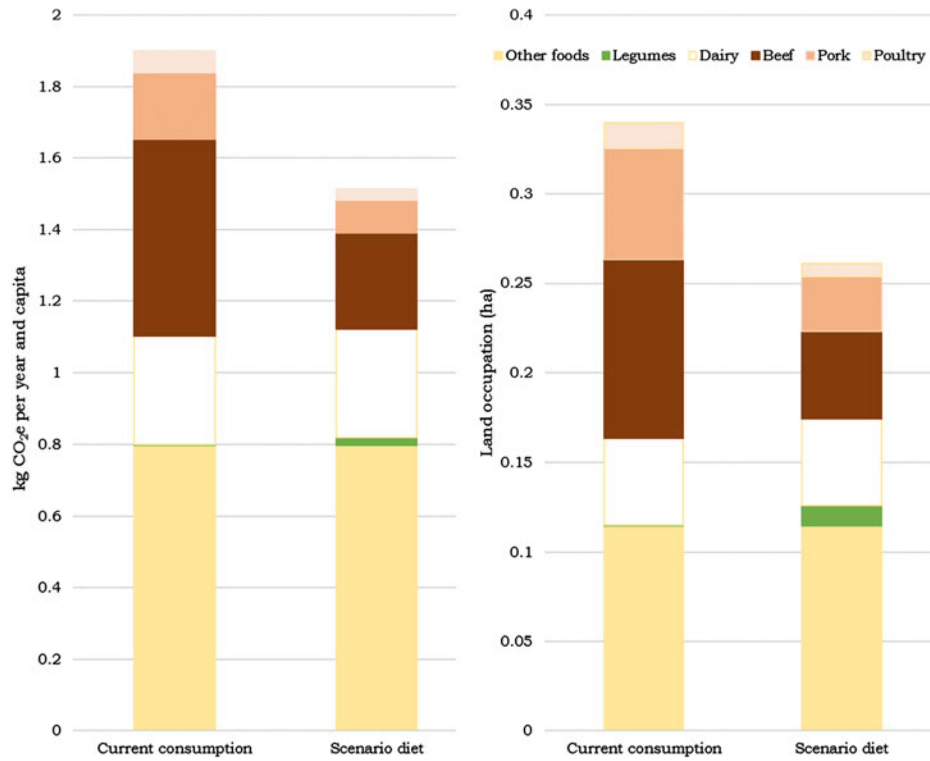

Fig. 4. Climate impact (a) and land use (b) of the current Swedish diet in a scenario in which meat consumption reduced by 50% and replaced by legumes.

In the scenario, approximately 5100 tons less mineral N would be needed in Swedish agriculture due to reduced need for cereals and oilseed crops for animal feed. Furthermore, if 25 kg less N fertilizer were applied per ha to non-legume crops grown after a grain legume (compared with after a non-legume pre-crop; Preissel *et al.*, 2015), an additional 700 tons of mineral N fertilizer could be saved as a result of the increased grain legume cultivation in the transition scenario. This potential reduction (5800 tons) corresponds to 3.5% of the total amount of mineral N fertilizer used in Swedish agriculture in 2016 (SS, 2017*d*).

Storage and spreading of manure give rise to acidifying emissions through ammonia volatilization. However, since the majority of all ammonia emissions from Swedish livestock production are associated with dairy and beef production (Vallin *et al.*, 2016), which are unaffected in the transition scenario (as domestic beef production is unaffected and only imports are reduced), ammonia volatilization within Sweden is only marginally affected (reduced by approximately 3%).

As the diet after transition contains less protein (6%) and hence less N, excretion of N will be lower, which in turn will affect wastewater composition. The N load to recipient waters from Swedish wastewater treatment systems is reduced by almost 1200 tons N per year in the transition scenario. Thus, dietary changes will affect eutrophying emissions through two pathways: land use change when less arable land is required for food production and lower N loads from sewage systems when total protein intake is reduced (Vallin *et al.*, 2016). In addition, the reduction in chicken and pig production means that less manure is produced, which also reduces the risk of eutrophication.

Challenges related to consumption: how to get more legume-based products on the market?

There are many other challenges than those related to primary production ('Impact on and challenges for agricultural production' section) which need to be overcome in implementing the scenario explored here. Increasing demand from consumers and the food industry is probably the first and most important driver to overcome current limitations in the cultivation and use of grain legumes in the Swedish food system. New market opportunities for legume-based foods and increased consumer awareness about the environmental and health benefits of legumes are reported to be important factors for increasing the price paid to farmers (Zander *et al.*, 2016). This mechanism would help to expand the cultivation of grain legumes, provided that an increase in consumer demand is met by domestic production.

In terms of consumer demand, there are positive developments. The Nielsen global consumer report for 2015 shows that food attributes such as 'fresh, natural and minimally processed' are increasingly important.[4] There is also a growing trend for vegetarian and vegan diets in many countries in the Global North. At the same time, there is a growing trend for ready-to-eat, fast-cooking, convenience food. In a scenario where meat consumption is reduced by 50% and replaced with legumes, the legumes will therefore also have to be incorporated into convenience foods, as it is unlikely that most consumers will alter their food habits to consume substantially more unprocessed plain legumes. In the scenario explored here, 80% of legume consumption is assumed to be based on the traditional animal feed crops faba bean and pea. A successful transition will thus require product development where these crops need to be processed into attractive food products that Swedish consumers accept as meat substitutes.

However, one potential obstacle for consumers as regards these novel convenience foods is higher price compared with

[4]See for instance Nielsen (2016), Consumers up their protein with quick and healthy meat alternatives, http://www.nielsen.com/us/en/insights/news/2016/consumers-up-their-protein-with-quick-and-healthy-meat-alternatives.html, retrieved on 2018-09-06.

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conventional products (De Marchi *et al.*, 2016). While grain legumes in raw form are typically a low-cost alternative, in processed form and as an ingredient in convenience foods legume prices are currently higher.

One key component of changing consumption and purchase patterns is knowledge regarding the environmental and health benefits of legume-based products (Lemken *et al.*, 2017). A recent study on consumer preferences in Finland found that, although beans and soy-based plant proteins are infrequently consumed in Finland, there is potential for using beans as a meat substitute in the 'meat-eating culture' of Finland (Jallinoja *et al.*, 2016). However, the proportion of consumers who plan to increase their bean consumption in the future is relatively low (20%). Consumers aged 25–34 are generally more inclined to eat beans, as are consumers living in cities and those with a higher education level. Knowledge about the benefits of legume food and about how to prepare tasty bean-based meals is important for increasing consumption of legumes.

A central challenge for the true potential of the scenario to materialize is that increased intake of legumes is not enough; meat consumption must also decrease substantially. Stoll-Kleemann and Schmidt (2017) list 11 influential factors behind the high level of meat consumption in developed countries. These include values and attitudes, but also social norms, roles and relationships. In addition, the 'food environment' or other personal, social and external factors may be important in explaining the existing meat eating culture. Besides subjective and social norms, price and availability are important in changing consumption patterns. If broader consumer groups, rather than small groups of health-conscious or vegetarian consumers, were to recognize that meatless foods can be linked to personal health, animal welfare and sustainability issues, then consumer habits and perceptions might gradually change and a new awareness and new social norms could be created. However, as this is a slow process, public policy options have also been suggested, including a tax on meat and dairy (Säll and Gren, 2015). Apostolidis and McLeay (2016) highlight the need to target interventions and policies for reduced meat consumption at specific consumer segments, rather than at the average consumer, as preferences for meat substitutes vary greatly between consumer groups.

A limiting factor at the food industry level is access to local facilities for intermediate processing or pre-treatment of legume grains to be included as functional ingredients, such as a flour or protein isolate. In this interface between raw material supply and processing into novel products, co-evolutionary mechanisms in the agri-food sector can be an additional reason why it is difficult to increase the use of grain legumes. Interdependencies among actors in the dominant cereal-based systems for production and processing are suggested to cause lock-in effects that hinder the development of alternative (legume-based) systems (Magrini *et al.*, 2016). Unlocking the system will therefore require, among other actions, investment in processing/pre-treatment facilities for other crops than the currently dominating commodities.

Conclusions

Reducing Swedish meat consumption by 50% and replacing it with a daily per capita consumption of 55 g domestically grown cooked grain legumes would bring many benefits. It would reduce the climate impact (−20%) and land use (−23%) associated with the Swedish diet, reduce the need for N fertilizer and the N load from wastewater plants, greatly increase fiber intake and improve folate intake from diets, and bring many agronomic benefits to Swedish cropping systems. However, achieving a large increase in the production of domestic grain legumes to supply the necessary legumes involves several challenges, such as lack of suitable varieties and difficulties controlling weeds, pests and diseases. The challenges are likely to be particularly pronounced for grain legume crops that are not yet well known to Swedish farmers, including lentils, gray peas and common beans. Nevertheless, the transition is technically feasible from an agronomic perspective based on available land and considering how grain legumes can be included in current crop rotations. Other challenges are lack of processing facilities to supply functional legume-based ingredients to food industries and low consumer awareness about the benefits of grain legumes. A successful transition according to our scenario requires the development of new attractive products acceptable as meat substitutes, made out of legumes that have traditionally been used as feed crops (pea and faba beans). Hence, a successful transition to more sustainable plant-based food systems would require concerted actions by many food system actors, including continued research on legume cultivation and processing and a diverse set of policy actions to reduce meat consumption and increase domestic grain legume production, processing and consumption.

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Annex

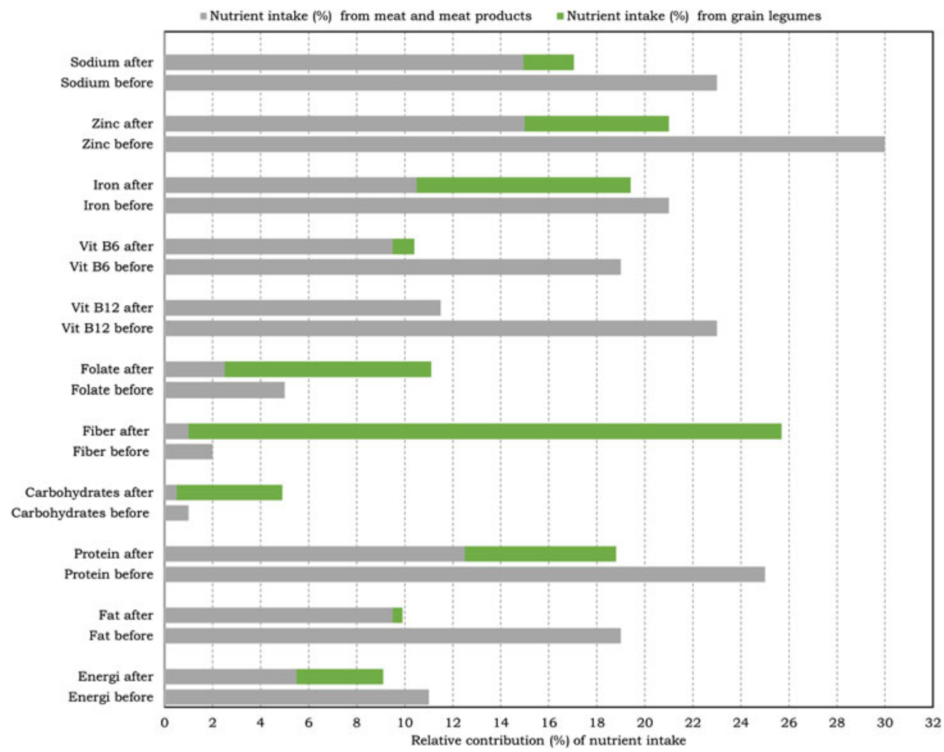

Fig. A1. Relative contribution (%) of nutrients from meat products (gray bars) plus substitute portion of grain legumes (green bars) after transition compared with current habitual meat intake before transition.

Table A1. Nutrient composition of raw dried grain legumes (per 100 g)

Nutrient	Broad beans *Vicia faba*	White beans *Phaseolus vulgaris*	Brown beans *Phaseolus vulgaris*	Red beans *Phaseolus vulgaris*	Mung beans *Vigna radiata*	Cow peas *Vigna unguiculata*	Chickpeas *Cicer arietinum*	Yellow peas *Pisum sativum*
Water (g)	12	11	11	11	11	11	11	*11*
Carbohydrate (g)	42	46	45	48	45	52	51	49
Fat (g)	1.7	1.6	1.5	1.5	1.3	1.5	4.8	1
Protein (g)	25	22	22	22	24	23	21	22
Total dietary fiber (g)	16	16	16	14	16	9.4	10	11
Folate (µg)	423	488	394	394	625	633	557	33
Calcium (mg)	102	144	135	110	118	74	150	59
Phosphorus	390	425	420	405	340	425	331	380
Potassium (mg)	1530	1530	1040	990	1050	1020	800	1100
Magnesium (mg)	192	184	131	163	170	230	160	120
Iron (mg)	7.1	5.5	5	7	7.7	5.8	6.9	6
Zinc (mg)	2.8	2.8	2	2.8	2.8	2	0.8	3.8
Selenium (µg)	2.2	2	2.2	2	2	2	5	2

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Table A2. Potentially positive and negative effects of anti-nutritional compounds on health

Compound	Potentially positive health effect	Potentially negative health effect
Enzyme inhibitors (trypsin, chymotrypsin and amylase inhibitors)	– Anti-inflammatory and anti-carcinogenic agent in the gastrointestinal tract – Amylase inhibitors slow down carbohydrate digestion, reduce the blood glucose and insulin response and thus could be used for therapeutic treatment of diabetes	– Interference with protein and carbohydrate digestion – Growth inhibition
Lectins (hemagglutinins)	– Reducing absorption of macronutrients, could be used for treatment of obesity – Reducing the blood glucose response	– Interference with macronutrient absorption – Growth inhibition – Blood agglutination
Oligosaccharides	– Reducing the risk of intestinal cancer, improving the immune system, increases stool excretion frequency and weight and increasing beneficial HDL cholesterol concentrations – Promoting the growth of beneficial gut microbiota (bifido bacteria)	– Gas-generating compounds (flatulent substances)
Phenolic compounds	– Antioxidant activity – Anti-inflammatory activity – Inhibition of enzymes α-amylase and amyloglucosidase reducing postprandial blood glucose	– Formation of less digestible tannin–protein complexes – Inhibition of digestive enzymes
Saponins	– Anti-carcinogenic and anti-mutagenic activity – Cholesterol-lowering effect	– Strong hemolytic activity
Vicine and convicine		– Blood hemolysis
Phytates and oxalates	– Anticarcinogenic activity – specifically for colon cancer	– Reducing mineral bioavailability by forming insoluble chelate complexes

Summarized from the following review articles: Campos-Vega *et al.* (2010), Champ (2007), Gulewicz *et al.* (2014) and Sánchez-Chino *et al.* (2015).

Table A3. Effects of food processing of legumes on content of nutrients and anti-nutritional compounds

	Soaking	Cooking/autoclaving	Germination	Extrusion
Nutrients	↓Soluble protein (insign) ↓Up to 10% fat ↓Starch (insign) ↓3–10% minerals ↑IVSD (insign) ↑5–15% TDF ↑40–60% folate ↑Mineral availability	↓Soluble protein (insign) ↓Up to 45% fat ↓Starch (insign) ↓Minerals (insign) ↑80–125% IVPD ↑80–125% IVSD ↑5–20% TDF ↑17–40% folate ↑Mineral availability	↓Soluble protein (insign) ↓Up to 25% fat ↑3–15% IVPD ↑20–40% IVSD ↑5–20% TDF ↑40–240% folate ↑Mineral availability	↓Soluble protein (insign) ↑20–25% IVPD ↑80–130% IVSD
Anti-nutrients	↓0–30% TIA ↓4–27% AIA No changes of HA ↓22–45% OS ↓49% phytate ↓23–87% tannin	↓23–100% TIA ↓80–100% AIA ↓75–100% HA ↓18–77% OS ↓64–91% phytate ↓0–95% tannin	↓15–75% TIA ↓34–48% AIA ↓0–18% HA ↓83–100% OS ↓16–96% phytate ↓13–76% tannin	↓86–100% TIA ↓100% AIA ↓98% HA ↓24% OS ↓8–40% phytate ↓9–90% tannin

Insign, insignificant; IVPD, *in vitro* protein digestibility; IVSD, *in vitro* starch digestibility; TDF, total dietary fiber; TIA, trypsin inhibitor activity; AIA, α-amylase inhibitor activity; HA, hemagglutinin activity; OS, oligosaccharides.
Summarized from the following publications: Alonso *et al.* (2000), Alonso *et al.* (1998), Azizah and Zainon (1997), Benítez *et al.* (2013), Chilomer *et al.* (2010), D'Souza (2013), Egounlety and Aworh (2003), Embaby (2010), Ghavidel and Prakash (2007), Hefnawy (2011), Hefni and Witthöft (2014), Hefni *et al.* (2015), Khattab and Arntfield (2009), Martínez-González *et al.* (2008), Nkundabombi *et al.* (2016), Pedrosa *et al.* (2015), Polak *et al.* (2015), Rehman and Shah (2005), Sandberg (2007), Shi *et al.* (2017), Shimelis and Rakshit (2007), Wang *et al.* (2008) and Luo *et al.* (2014).

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