# CROPQUEST

# Indigenous supply of plant–based proteins for Ireland

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## 1 Introduction to plant based protein

Humans have used plant-based foods as a source of protein for millennia, providing about 67% of total protein intake globally {Miller, 2013 #711}. The majority of plant–based proteins are obtained from cereals and legumes with both quantity and quality of protein determining the adequacy of meeting protein requirements {Day, 2013 #483}. This is due to the fact that most plant–based proteins are deficient in one or more of the indispensable amino acids required for proper human development {WHO, 2002 #519}. This issue is generally alleviated by mixing different complementary plant protein sources, one source providing the amino acid that is limiting in another source and vice versa, thereby creating a complete source of amino acids {Miller, 2013 #711}.

Protein malnutrition remains a significant public health problem in many areas of the world with it been recently estimated that there is a 10% to 30% risk of protein inadequacy in sub Saharan Africa and parts of Asia {Ghosh, 2013 #492}. Protein malnutrition can be caused due to some plant-based foods containing inhibitors that reduce protein digestibility. It is found that cereals and legumes contain phytates and other factors which may inhibit the absorption of trace minerals. These inhibitors can be inactivated by heat processing, however diets high in these foods may increase the risk for certain micronutrient deficiencies {Miller, 2013 #711}.

The continuing rise of global population from the current 7.2 billion to 8.2 billion by 2025 and to 9.6 billion by 2050 {United Nations, 2012 #459} has necessitated the urgent need to identify and develop sustainable solutions to increase the availability of high–quality food protein {Wu, 2014 #520}. The Food and Agriculture Organization (FAO) of the United Nations has estimated that globally 165 million children suffer from stunted growth, overall, over one billion people worldwide have inadequate protein intake {FAO, 2014 #488}. These dietary deficiencies highlight the need for expansion of protein-rich plant crops for human and animal consumption {Wu, 2014 #520}.

The protein deficit in Europe has fluctuated between 70% and 80% over the past forty years (Figure 1). The majority of this deficit was imported as soybean to be incorporated into feed diets of animal and marine production systems.

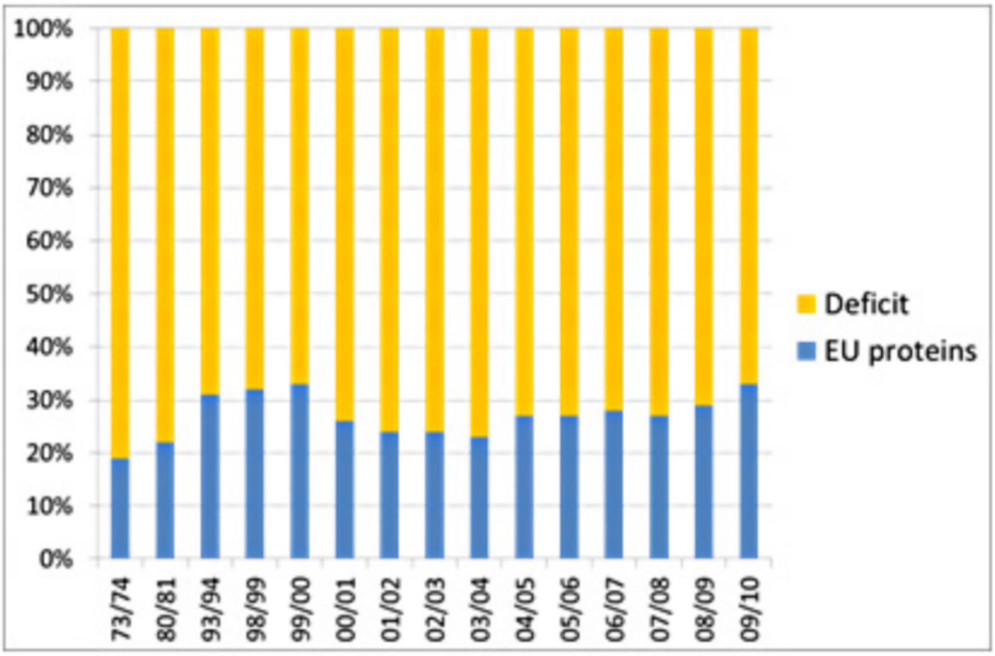


**Figure 1 Evolution of EU protein deficit {Martin, 2014 #501}.**

The European Union used nearly 29.4 million tonnes of soybean meal in 2011 {Martin, 2014 #501} which accounted for the consumption of about 14% of the world's soya crop with European consumption of soya on a per capita basis amongst the highest in the world {Comittee on Agriculture and Rural Development, 2013 #688}. Only 2% of arable land in the European Union is now used to grow protein crops (grain legume species such as faba bean, pea, chickpea, lupins and soybean), with the proportion of all arable land dedicated to growing protein crops declining from 4.7% in 1961 to 1.8% in 2013 (Figure 2) {Committee on Agriculture and Rural Development, 2013 #688}.

Ireland's ambitious Food Harvest 2020 plan of growing agri-food exports to €12 billion by 2020 {Department of Agriculture, 2014 #437} has placed a large demand for sustainable protein sources to balance the animal nutritional requirements while increasing production. The largest of these production increases will be in the beef and dairy sectors {Department of Agriculture, 2014 #437}. Protein is now regarded as the most valuable component of milk due to ongoing change in market demand influence and consumer diet preferences {Murphy, 2009 #694}. Ireland's and the EU's dependence on imported protein sources such as soya bean meal (SBM) has initiated a legislative and political push towards the development of indigenous plant–based protein sources {Department of Agriculture, 2014 #437}.

This report aims to review the scientific literature on high–value products to underpin and support the development of an indigenous Irish plant-protein sector.

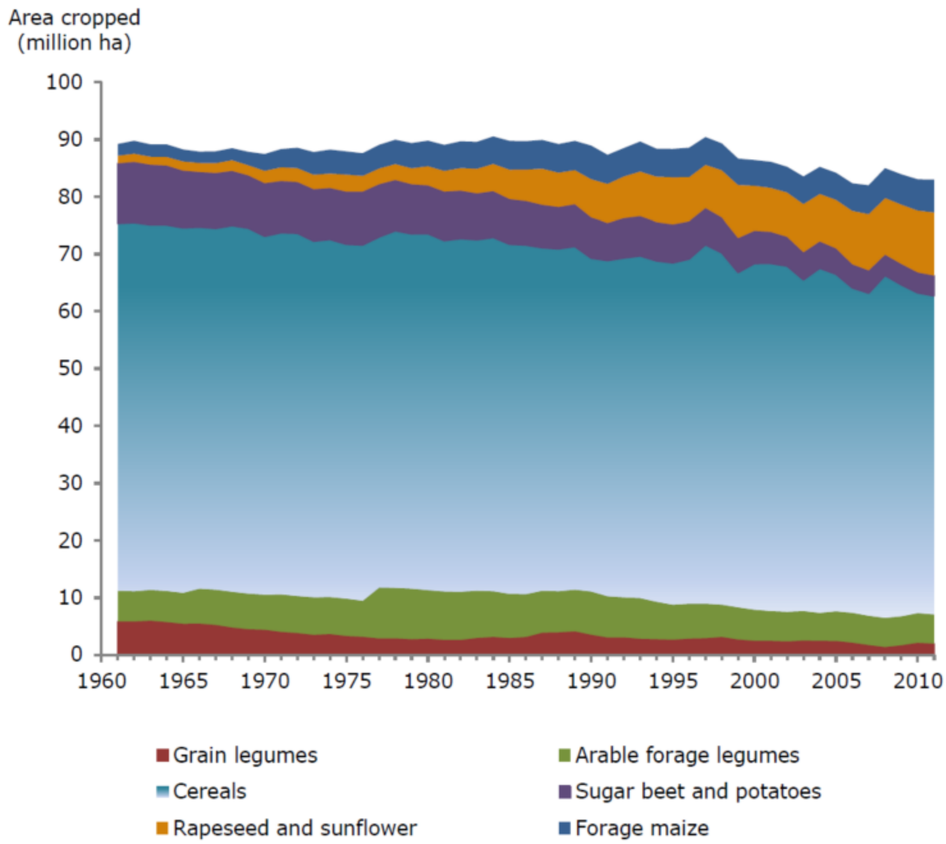


**Figure 2 Change in areas of production of key arable crops in the EU–27 (1961 – 2011) {Comittee on Agriculture and Rural Development, 2013 #688}.**

## Drivers and threats towards protein crop production in Ireland

The EU Committee on Agriculture and Rural Development {, 2013 #688} key market developments that have started to shift the dynamic in Europe for indigenous production of plant–based proteins. These market developments include:

***Nitrogen fertiliser has become more expensive***

The economic benefit of nitrogen provision via fixation through legumes is increasing. This is precipitated by an over 300% increase (Figure 3) in nitrogen fertiliser prices since 2000 which has resulted in the costs of fertiliser N relative to farm prices for wheat and milk to increase by 78% and 63%, respectively {Committee on Agriculture and Rural Development, 2013 #688}.

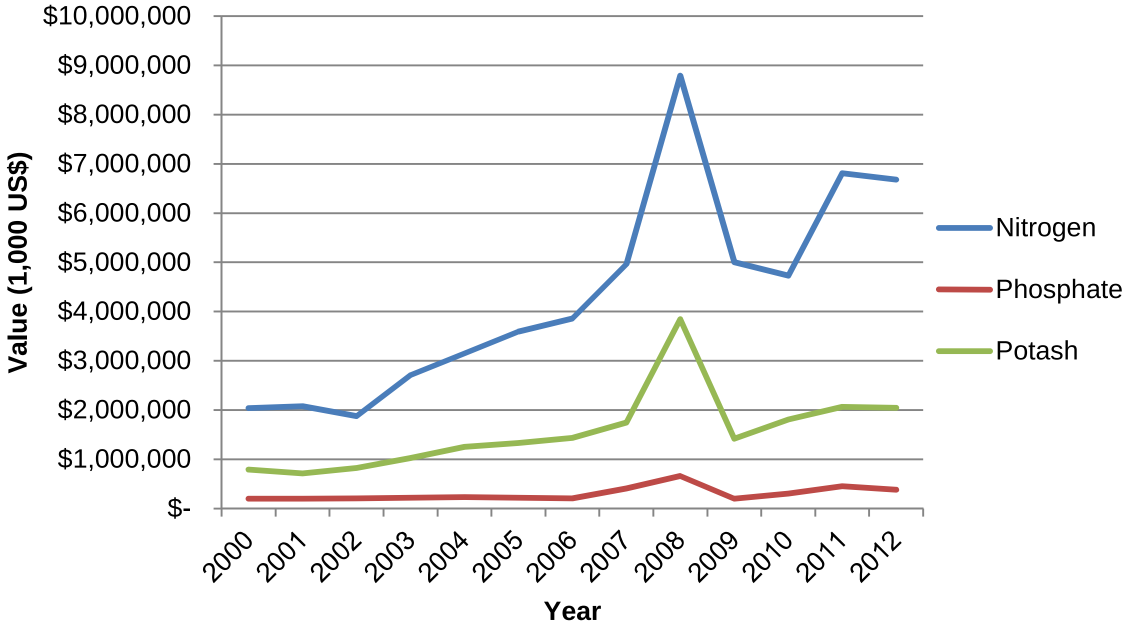


Figure 3 Changes in the price of mineral fertilisers (nitrogen, phosphate and potash) since 2000 {FAO, 2015 #622}.

***The price of soya on the world market is increasing***

The price paid for imported soya has more than doubled since 2000 (Figure 4). Soya feed prices are expected to continue to increase due to growing international demand {Committee on Agriculture and Rural Development, 2013 #688}. If the EU were to have one quarter of its soya imports GM-free, the increased demand would raise the price of GM free soya by 55 € $t^{-1}$ {Aramyan, 2009 #480}.

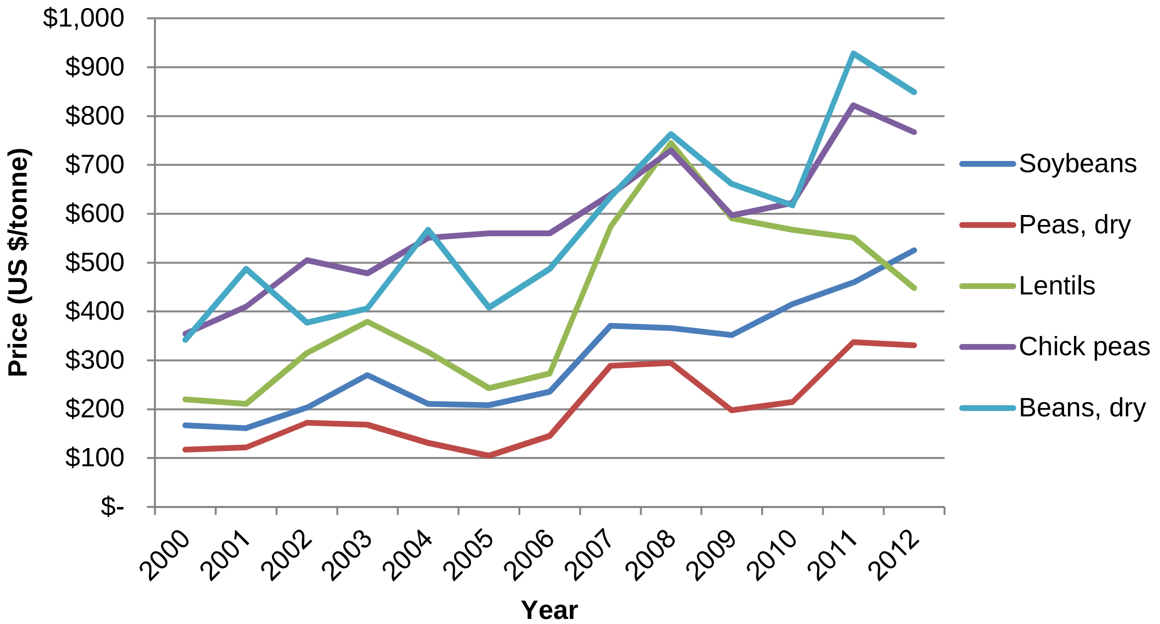


Figure 4 Changes in the prince of the major plant protein sources since 2000 {FAO, 2015 #622}.

***Increasing producer prices for protein crops in Europe***

The prices of European–grown protein crops used for animal feed are closely correlated with the price of imported soya bean (Figure 4). This corresponding price increase has resulted in a price advantage of protein crops over wheat, reducing the comparative advantage of wheat (and cereals in general) over protein crops in competition for European land {Committee on Agriculture and Rural Development, 2013 #688}.

The highlighted recent developments run counter to over 50 years of declining protein production. This decline can in part be attributed to the comparative advantage of growing cereals in Europe. A major underlying driver behind the reduction in the proportion of arable land used for protein crops is the increased comparative advantage in the production of starch–rich cereals in Europe over the production of protein–rich grain legumes. Wheat yields in Europe have increased steadily and are now double those of soya bean and other protein crops, thus since 1961, the comparative advantage of using European land to grow wheat instead of protein crops has increased dramatically (Figure 5) {Committee on Agriculture and Rural Development, 2013 #688}.

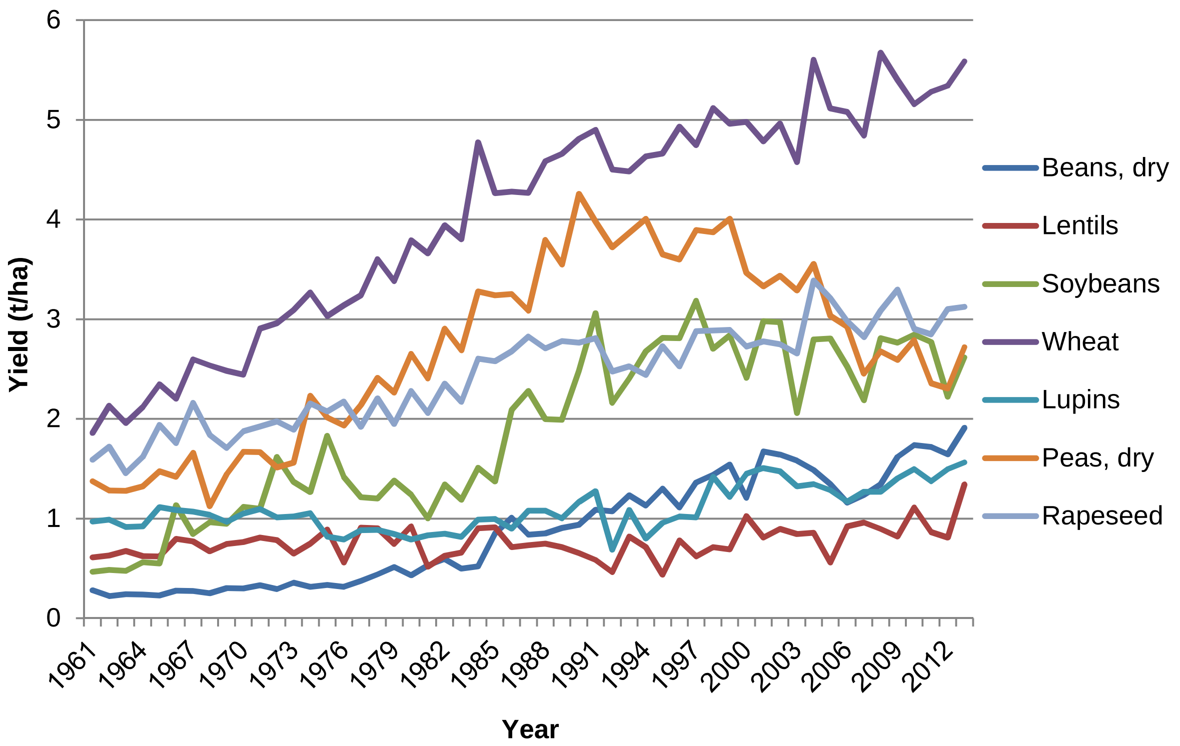


Figure 5 Average yields of wheat and the main grain legumes in the EU–27 (1961 – 2013) {FAO, 2015 #622}.

## Crops for protein production

### Pulses: peas, beans, chickpeas and lupins

Pulses including pea, lupin, chickpea, lentil, bean, and other dry edible seeds from the pods of legume plants are important sources of protein in many diets around the world. Pea is the major pulse protein source and is exploited extensively as an important source of commercial proteins. This extensive exploitation is due to the fact that it can be cultivated all over the world and its hull is easily removed. Chickpea is one of the most important pulse crops consumed in the Indian sub–continent whereas, yellow lupins grown in Europe and South America are mostly used for animal feed.

Peas and chickpeas contain similar high levels of protein and carbohydrates, with peas having relatively high concentrations of insoluble dietary fibre and low concentrations of fat (Table 1). On average, peas contain 25% protein but with a wide variation between plants, species and varieties. Lupins contain a higher protein content and are in a similar range to soybean, at about 40% (Table 1), and they have a high fibre content {Evans, 1993 #681}. Direct food use of yellow lupins is prevented by the presence of quinolizidinic alkaloids, which may be removed by soaking. However, white lupins, commonly consumed in the Mediterranean countries, are primarily grown for direct food uses {Day, 2013 #483}.

**Table 1:** Protein contents of the major plant protein sources (adapted from Day {, 2013 #483}).

| Plant source | Protein content (%) | Starch content (%) | Lipid content (%) | Non–starch polysaccharides (%) |
|---|---|---|---|---|
| Wheat (flour) | 8 – 15 | ~75 | 1 – 2 | ~5 |
| Rice | 7 – 9 | 90 | - | - |
| Soybean | 35 – 40 | - | ~20 | ~30 |
| Pea | 20 – 30 | 60 – 65 | - | ~5 |
| Chickpea | 20 – 25 | ~60 | - | ~10 |
| Lupin | 35 – 40 | - | ~10 | 35 - 40 |
| Rapeseed | 17 - 26 | - | 40 | 12 – 30 |

Three forms of pea protein ingredients are produced commercially: pea flour, pea protein concentrate and pea isolate (Table 2). Pea flour is produced by dry milling of de–hulled peas. Pea protein concentrate is produced by dry separation methods; whereas pea protein isolate is produced by wet processing using either alkali or acid solubilisation, followed by isoelectric precipitation or an ultrafiltration process which produces a protein fraction with a much higher protein content of 85 – 95% {Boye, 2010 #683}.

Similar techniques to that of pea proteins for concentrating the protein fraction from chickpea flour with the isolated chickpea protein appearing to have good emulsification properties {Boye, 2010 #683}{Karaca, 2011 #687}.

Two major protein fractions may be produced by wet milling of lupins. The fraction produced by alkaline extraction and isoelectric precipitation has good emulsification properties, whereas the fraction recovered by ultrafiltration of the remaining supernatant has good foaming properties {Duranti, 2008 #699}. When lupin protein is extracted, the resulting protein isolate is free of alkaloids and therefore can be used as a functional ingredient in human food {Day, 2013 #483}. When extracted, lupin flour and protein isolates are free of alkaloids. These ingredients have been successfully tested in muffins in which egg and milk proteins are totally substituted; in biscuits to achieve high protein contents; and in dairy, bakery and meat products {Drakos, 2007 #690}{Pollard, 2002 #698}.

**Table 2**: Major industrially produced protein ingredients from plant sources (adapted from Day {, 2013 #483}).

| **Plant source** | **Protein products** | **Protein content (%)** | **Price ($ ton$^{-1}$)** | **Major manufacturer and/or supplier** |
|---|---|---|---|---|
| Soy | Soy protein conc. (SPC) | 65 – 70 | 800 – 3,000 | www.solae.com |
| | Soy protein isolates (SPI) | >90 | 1,000 – 5,000 | www.adm.com |

| | | | | |
|---|---|---|---|---|
| | Textured soy proteins | 60 | 800 – 1,500 | www.cargill.com |
| Wheat | Vital wheat gluten (VWG) | 75 – 80 | 1,000 – 1,500 | www.manildra.com |
| | Isolated wheat protein (IWP) | 90 | – | www.mgpingredients.com |
| | Texturised wheat proteins | | 1,400 – 1,600 | www.cargill.com |
| | Enzyme hydrolysed protein | >90 | 1,000 – 8,000 | |
| Rice | Rice protein conc. | ~ 80 | 1, 000 – 2,000 | www.foodchem.cn |
| | Rice protein isolate | 90 | 2,000 – 4,100 | |
| Peas | Pea protein conc. | 85 – 90 | ~1,350 | www.nutripea.com |
| | Pea protein isolate | | 2,000 – 5,000 | www.roquette.com |
| Rapeseed | Rapeseed protein isolate | 90 | – | www.bioexx.com |
| | Hydrolysed proteins | 83 | – | www.burcon.ca |
| Potato | Potato proteins | | 1,000 – 5,000 | www.solanic.eu |

Applications of pea proteins are found in a range of food products such as cereal and bakery products, nutritional snack bars, pasta, meal replacement beverages, baby food formulations, vegetarian applications, meat and seafood products {Day, 2013 #483}. The increasing prevalence of pea proteins is primarily due to its positive fat– and water–binding capabilities, emulsification properties and gelation, texture and nutritional values {Sandberg, 2011 #685}{USA Dry Pea and Lentil Council, 2013 #682}. Pea protein concentrate may be used as an ingredient for producing non–fat dry milk replacement for the bakery industry and its main use in meat products is in meat patties, hamburgers and sausages {Sandberg, 2011 #685}.

Pea starch is high in amylose, which allows it to form opaque gels to make starch noodles; however; it can also be used to thicken soups and sauces and to provide texture in gluten-free baked goods and frying batters as well as meat applications {USA Dry Pea and Lentil Council, 2013 #702} and good substitutes for soy proteins {Barac, 2011 #691} and replacements for egg proteins {Pelgrom, 2013 #686}. Interest in pea protein ingredients has gained traction during the last five years, and pea concentrates and isolates have begun to emerge, some of which are soluble and can be used in low pH beverages and ready–to–drink products, providing a highly digestible protein at competitive prices {Barton, 2014 #506}.

Applications of chickpea flour as a potential high protein source for use in emulsified meat products is due to its superior technological functionality and minimal effects on flavour {Sanjeewa, 2010 #712}. It is considered that both the protein and the starch component of chickpea flours have been regarded as valuable sources due to their versatile functionalities {Ma, 2011 #707}. Lupin flour (i.e. free of alkaloids) and protein isolates have been successfully tested as ingredients in various food products such as in muffins in which egg and milk proteins are totally substituted; in biscuits to achieve high protein contents; and in dairy, bakery and meat products {Drakos, 2007 #690}{Pollard, 2002 #698}. Two major protein fractions may be produced by wet milling. The fraction produced by alkaline extraction and isoelectric precipitation has good emulsification properties, whereas the fraction recovered by ultrafiltration of the remaining supernatant has good foaming properties {Duranti, 2008 #699}.

Overall, the market share for protein from pulses is relatively small when compared with soy and wheat-based protein ingredients (Figure 6), however, it has been steadily growing over the last 4 years and according to {Barton, 2014 #506} is now poised to expand and take greater market share. Several leading pea protein manufacturers, including Burcon, Coscura, and Fenchem Biotek, are in the process of expanding their production capacity to meet market demands. Western Australia has now become the largest grower of lupins, producing more than 85% of world's lupin crop and exports most of it as animal feed {Day, 2013 #483}.

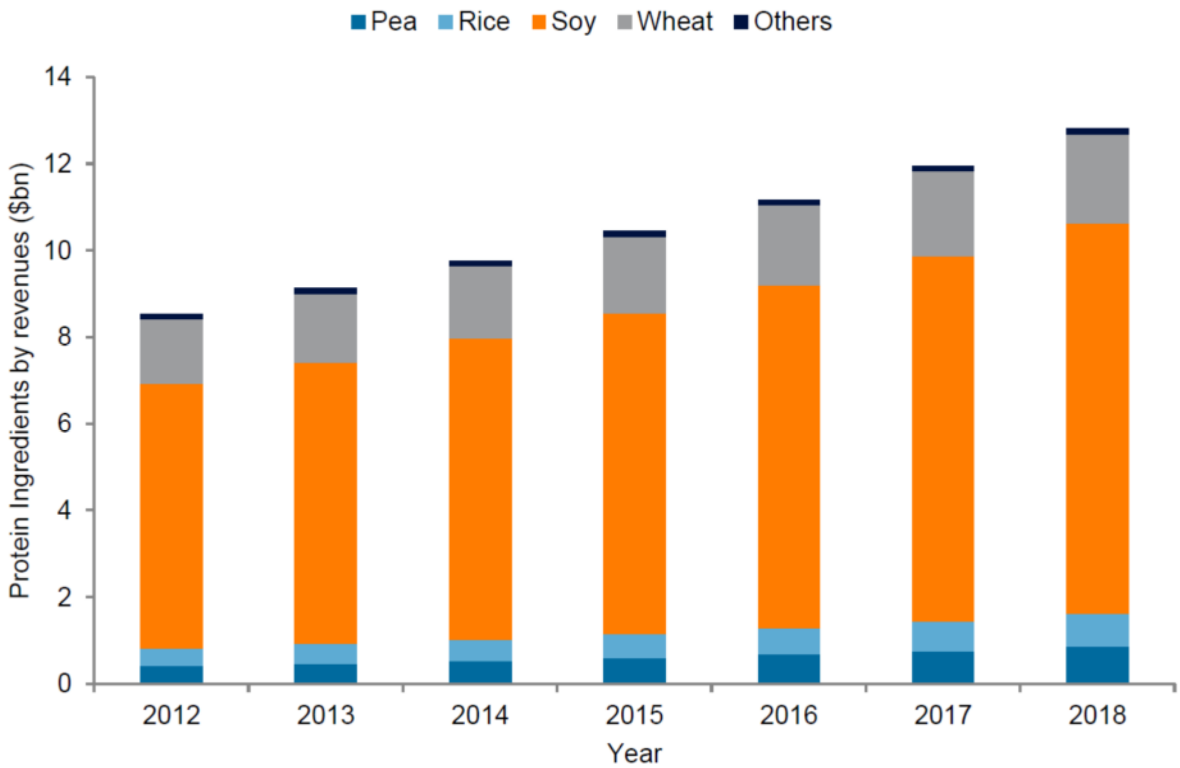


**Figure 6 Global plant protein ingredients market by source {Barton, 2014 #506}.**

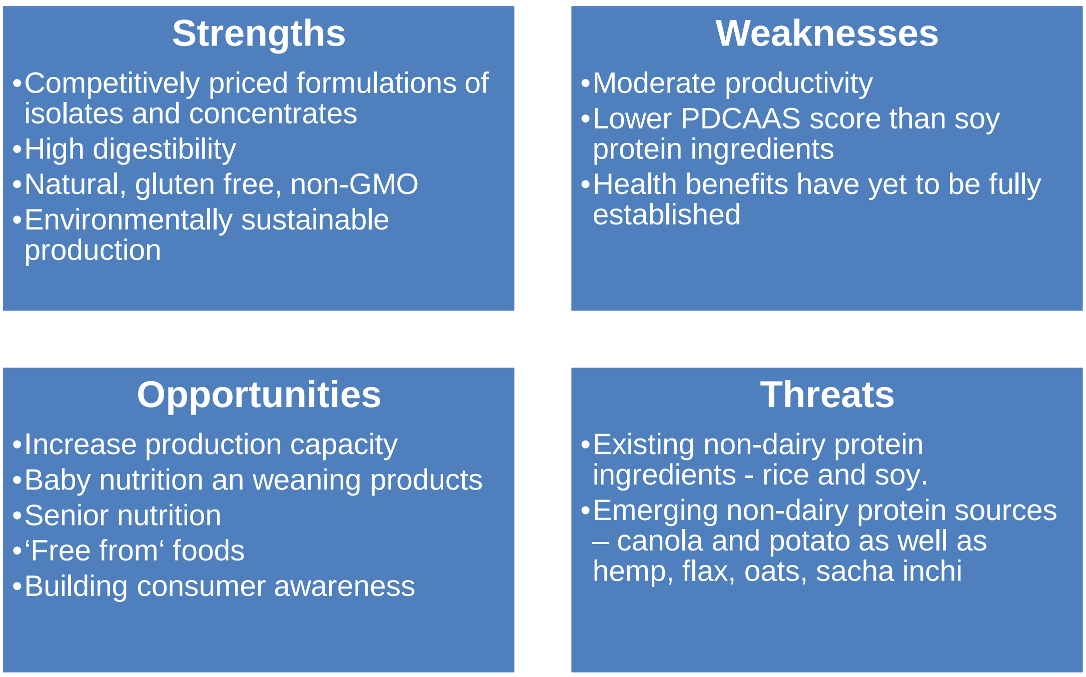


Figure 7 SWOT analysis of protein from pulses for ingredients {Barton, 2014 #506}.

## Oil–based crops: rapeseed and sunflower

Rapeseed, also known as Canola, is commercially the second most important oil seed, after soybean, in the world {FAO, 2015 #622}. Canola's protein content is lower than soybean, in the range of 17 – 26%. With increasing production of canola oil worldwide, the quantities of canola meal (a byproduct after oil extraction) is also increasing. However, protein–rich canola meal is currently almost solely used as a protein source in livestock and aquaculture feedstuffs. The high contents of glucosinolates, phenolics and phytates (which are beneficial to growing plants) left in canola meal limit its use for human consumption {Tan, 2011 #713}.

With the development of more sophisticated protein extraction and fractionation processes such as ultrafiltration and membrane separation production of protein isolates with protein contents of > 80% and with most of the undesirable chemical compounds removed from the product are possible {Logie, 2010 #720}{Xu, 2002 #714}. Commercial producers (Table 2), have reported that canola protein isolates are suitable for use in beverages, dressings and sauces, meat substitutes, baked goods and protein snack bars. The gelling properties of canola protein isolates provide the potential for it to be used in comminuted meat products. An attractive characteristic of canola protein is its well–balanced amino acid composition allowing for it to be used to complement cereals that tend to be low in lysine and to improve the nutritional quality of baked products {Arntfield, 2011 #721}.

Manufacturers have developed methods to produce canola (rapeseed) isolate with a balanced amino acid profile that can provide adequate levels of all the essential amino acids, resulting in 'Protein Digestibility Corrected Amino Acid Scores' (PDCAAS) of around 1, comparable to whey proteins {Arntfield, 2011 #721;Logie, 2010 #720;Tan, 2011 #713}. Unlike other sources of plant proteins, canola isolates are rich in methionine and cysteine, which play important roles in wound–healing {Tan, 2011 #713}. Canola has low levels of anti–nutritionals, does not contain phytoestrogens, and has antioxidant activity. Canola protein has good whipping functionality, making it an attractive substitute for egg protein. Two companies lead this field, BioExx Specialty Proteins and Burcon NutraScience (both of whom are based in Canada).

BioExx Specialty Proteins Ltd has developed two canola products: Isolexx, which is a protein isolate (80% protein), and Vitaless, a hydrolyzed canola protein. Isolexx has good solubility, strong foaming and emulsification characteristics, a balanced amino acid profile (PDCAAS score of 1), and high digestibility (95%). It has self–affirmed GRAS ("Generally regarded as safe") status in the US and can be incorporated into a wide range of products, from high protein nutrition bars to bakery products, meat, and vegetarian meals {Wanasundara, 2011 #517}. In contrast Vitaless is 100% soluble in water and is suitable for use in nutritional beverages, healthy foods, and nutritional bars. Similar to Isolexx, it is highly digestible (98%) and has a PDCAAS score of 1. According to reports from the company, the hydrolysis process lowers the prospective risk of immunological response, making it more appropriate for sensitive immune systems.

Burcon has developed the canola derived proteins Puratein and Supertein, these proteins are GRAS–notified in the US and have a novel food status in Europe. Burcon's has patented a process which separates the two naturally occurring proteins found in canola, namely cruciferin and napin, to create two distinct protein ingredients with separate and distinct nutritional and functional profiles that allow them to be used in a broader variety of food and beverage applications {Wanasundara, 2011 #517}. Burcon has teamed up with ADM to commercialize the canola proteins, which are highly soluble and suitable for functional drinks and waters. Tivall, an Israeli company, is also looking at ways to extrude canola protein to provide novel textures and flavors.

Globally, sunflower seed is the third major source of edible oil (after soybean and rapeseed) {FAO, 2015 #622}. Lipids are the major component of sunflower seed. Sunflower seed is also high in protein with the dehulled seed consisting of about 20 – 40% crude protein {Gonzalez-Perez, 2007 #715}. Protein content is, however, strongly influenced by the variety of the sunflower. The main use of sunflower seed is in oil extraction and one of the by–products of the oil extraction process is sunflower meal, which has a high protein content. The high protein content of sunflower meal makes it a suitable source of proteins, however, the suitability of the proteins for food applications is dependent largely on the oil extraction method used. Owing to the solvent extraction and high temperature (during expelling and desolventising/toasting) processing, the proteins are denatured to a large extent, resulting in the meal with a high content of insoluble proteins. Thus, the main use of sunflower proteins is in animal feed {Gonzalez-Perez, 2007 #715}.

**Proteins from tubers: potato**

The potato is a versatile, carbohydrate–rich food which is widely consumed worldwide in a variety of ways. Potato is not typically considered to be a good dietary protein source due to its low overall protein content which is around 1 – 1.5% of tuber fresh weight {Camire, 2009 #716}. However, potato is widely used for industrial starch production. The starch production process generates an aqueous by–product, known as potato fruit juice which contains most of the tuber soluble protein {Bartova, 2009 #717;Vikelouda, 2004 #719}. The potato juice is pretreated and absorbed, allowing the fractionation of potato proteins. Protein from potato has a relatively high nutritional quality and, therefore, has a high potential for utilisation in food products {Vikelouda, 2004 #719}. The recovery of potato protein from such a dilute aqueous system is a challenge in terms of economic returns. Therefore, mild less harsh isolation processes are preferred to recover the protein in a non–denatured form in order to preserve its solubility, foaming and emulsifying properties {Bartova, 2009 #717}{van Konigsveld, 2001 #718}{Vikelouda, 2004 #719}. Potato protein ingredients are now available in commercial products (Table 2) and can be used in a wide range of food applications including meat–free analogues, gluten–free bakery products, dairy–free ice–cream and toppings and desserts etc.

Solanic BV (AVEBE Group) is one of the leading potato protein ingredient manufacturers and markets Pro Go, an allergen–free, potato–derived isolate with good functionality (solubility, foaming, emulsification, and gelling) that is priced at a premium similar to whey protein isolates due to low volume and high demand from the food and drink industry. During 2013, the company received authorization from the EU to use proteins derived from potato as a wine clarification substance – this could open up a new market for potato proteins. Other applications of potato proteins include being utilized as meat replacers and low calorie alternative in puddings and instant beverages and non–dairy desserts (sorbet and ice cream) aimed at weight–conscious consumers {Camire, 2009 #716;Vikelouda, 2004 #719}. Potato protein isolates have also been incorporated into sports nutrition and supplements to support muscle synthesis and counter fatigue; for example, in 2013 Genuine Health launched a range of supplements, Activfuel+, Activerecover+, and vegan proteins specifically designed for sports enthusiasts. Potato protein extracts can be used as 'natural' emulsifiers in skincare products. Roquette is also broadening its scope and is also evaluating potato–based protein ingredients in its Proteov program.

While the development of canola and potato protein ingredients is still in its infancy, they may provide companies with alternative routes for product development. For example, canola protein is rich in sulfur-containing cysteine, which is known to be good for skin and nails, and potato protein is a natural emulsifier; these allergen–free, 'natural' ingredients may have a role to play in beauty and body–care products. According to Datamonitor's Market Opportunities in Gluten–Free (November 2013, CM00234-027), many US consumers are actively seeking to purchase gluten–free beauty and body–care products; this market was estimated to be worth $155.5m in 2013, growing by 37% per annum.

## Market analysis of plant-based protein potential

### Human consumption

The majority of consumers now consider protein as vital for a healthy lifestyle {Barton, 2014 #506}. Rapidly increasing populations with increasing incomes have led to an increase in the consumption of animal proteins over the last number of decades {Boland, 2013 #772}{Aiking, 2011 #478}. Sweden, the UK and the Netherlands are studying policies to decrease meat and dairy consumption for health and environmental reasons {Aiking, 2011 #478}. A growing number of consumers are consuming protein, from both meat and plant sources, as part of a healthy diet and for the control of weight {Barton, 2014 #506}. {Barton, 2014 #506 } has also reported that more and more consumers are reducing their consumption of meat products and opting for plant based diets. The average growth rate of plant proteins between 2013 and 2018 is expected to be 6% per annum.

As plant proteins have less of an environmental impact than animal based proteins {Aiking, 2011 #478}, and as such plant proteins are becoming more mainstream sources of proteins for consumers. With the global population expected to reach 9 billion by 2050 {UN, 2014 #514;United Nations, 2012 #459}, and increasing consumption of proteins per capita there will be a huge expansion for plant based proteins in the near future. Manufacturers are now looking to increase the protein content of their food products in an effort to appeal to these consumers.

### Plant protein potential in aquaculture

Continued growth and intensification of aquaculture production depends upon the development of sustainable protein sources to replace fish meal in aquafeeds {Gatlin, 2007 #491}. To be a viable alternative feedstuff to fish meal in aquafeeds, a candidate ingredient must possess certain characteristics, including wide availability, competitive price, plus ease of handling, shipping, storage and use in feed production. Furthermore, it must possess certain nutritional characteristics, such as low levels of fibre, starch, especially non–soluble carbohydrates and anti–nutrients, plus have a relatively high protein content, favourable amino acid profile, high nutrient digestibility and reasonable palatability {Gatlin, 2007 #491}.

**Table 3**: Proximate and nutrient content (as-fed basis) of fish meal, targeted ranges in alternative ingredients derived from grains and oilseeds (adapted from Gatlin et al. {, 2007 #491}).

| Category/nutrient | Fish meal (menhaden) | Target range for alternative ingredient | Barley | Rapeseed | Lupin | Field Peas | Wheat |
|---|---|---|---|---|---|---|---|
| Dry matter (%) | 92 | - | 88 | 93 | 89 | 89 | 88 |
| Crude protein (%) | 65 – 72 | 48 – 80 | 14.9 | 38.0 | 39.2 | 25.6 | 12.9 |
| Crude lipid (%) | 5 – 8 | 2 – 20 | 2.1 | 3.8 | 10.3 | 1.3 | 1.7 |
| Fibre (%) | < 2 | < 6 | - | - | - | - | - |
| Ash (%) | 7 – 15 | 4 – 8 | 2.9 | 6.8 | 2.8 | 3.4 | 1.6 |
| NFE (%) | < 1 | < 20 | - | - | - | - | - |
| Starch (%) | < 1 | < 20 | - | - | - | - | - |
| Non-soluble CHO (%) | None | < 8 | - | - | - | - | - |
| Arginine (%) | 3.75 | > 3.0 | - | - | - | - | - |
| Lysine (%) | 4.72 | > 3.5 | 0.44 | 2.27 | 1.4 | 1.5 | 0.36 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Methionine (%) | 1.75 | > 1.5 | 0.16 | 0.7 | 0.27 | 0.21 | 0.21 |
| Threonine (%) | 2.5 | > 2.2 | - | - | - | - | - |
| ω-3 fatty acids | ~ 2% | * | - | - | - | - | - |

*The fatty acids provided by alternative protein feedstuffs vary considerably and liquid supplements will be the primary source of fatty acids.