Opportunities in plant based foods – PROTEIN

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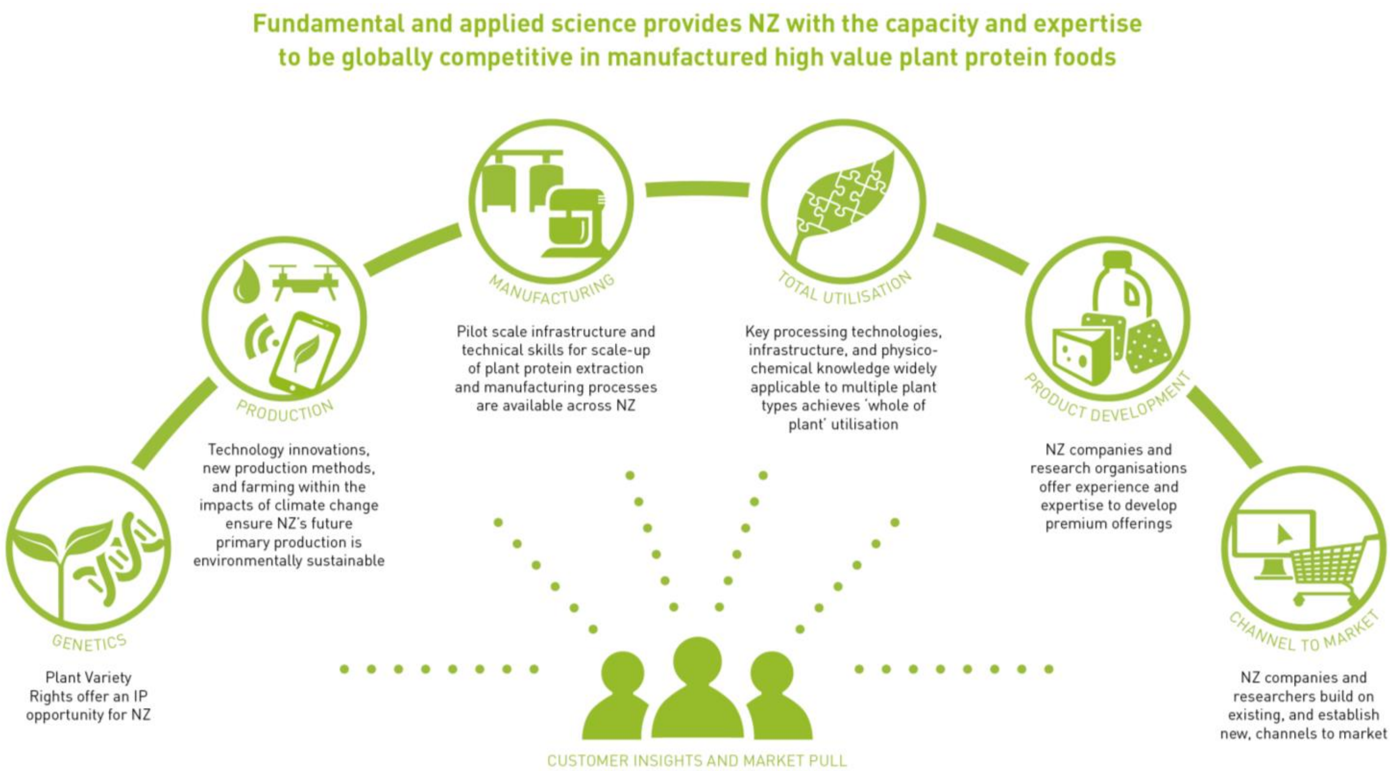
May 2018



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EXECUTIVE SUMMARY

Opportunities in plant based foods – PROTEIN

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New Zealand's current protein production is focused on proteins sourced from dairy and meat. There is ongoing discussion in society and industry on where the sustainability limits are for meat and dairy production in New Zealand, and what role diversification of protein sources to include plant-based protein might play in our premium future foods. Moves to tax carbon emissions from agriculture are likely to reduce the profitability of livestock farming, whilst lower emissions from plant-based food production systems mean their profitability will be less affected. Similarly, the water and nitrogen footprints of plant production are many times less than those of livestock farming, and the nutrient 'leakiness' of plant production systems is lower. Therefore, many niche locations are potentially more suitable for plant-based protein production than animal-based protein production. Crops that require fewer inputs than dairy or meat should be integrated into crop rotations to reduce the future environmental impact of New Zealand's annual land use cycle and export food production.

To take advantage of the new consumer trends towards plant-based foods and "flexitarian" lifestyles, there are significant opportunities for New Zealand to expand and develop plant-based protein sources. While soy and lupin are the two highest protein producers on an as-harvested basis, they are also challenging to grow in New Zealand because of their GM status and climatic requirements respectively. New Zealand-grown crops that could be more immediately used as protein sources for human consumption include alfalfa (lucerne), barley, beans, canola, hemp, kumara, linseed, white maize, oats, peas, potato, walnut, and wheat.

One of the challenges for plant protein ingredients isolated from single crops remains their "incomplete" essential amino acid content. Therefore, combinations of protein sources are often required to deliver a complete diet. However, these combination proteins tend to include ingredients with lower quality scores, which can affect the sales price of the ingredients and potential returns to producers and growers. Plant crops that show significant potential as sources of high quality protein for ingredient and food production in New Zealand include, alfalfa, amaranth, cereals, kiwifruit seeds, oilseeds, potato, tree nuts, and wrinkled peas.

Many of the requirements for isolating and manufacturing plant proteins are similar to those for dairy proteins, so expertise from the dairy industry could be applied to develop a new plant-based protein food industry in New Zealand. Our challenge is to extract and apply the engineering expertise and manufacturing capabilities currently held within our dairy industry to develop new opportunities in plant-based proteins. The majority of plant proteins used in the New Zealand food industry are currently manufactured overseas.

The high demand for plant proteins is still driven by their use in new product development (NPD) in the developing vegetarian/vegan foods sector. Although significant NPD has occurred to date, many of the plant protein foods are of lower sensory quality than their dairy-based equivalents. There remains therefore, a significant opportunity to develop new food technologies and functionalities for plant-based protein foods with higher consumer acceptability. Functional plant proteins with nutritional attributes continue to meet specific market needs and avoid becoming commoditised. This premium positioning suits New Zealand's globally niche food manufacturing sector.

New Zealand has led the thinking on "total utilisation" from the early 1970s when we pioneered the value-add from dairy waste streams by producing whey. Following this approach, it is timely also to recognise that isolation of proteins from plant sources is most economical when the protein component is one of a number of products isolated during a manufacturing process. Many of the materials that could be used to produce plant proteins are themselves "by-products" or "waste streams" from the production of other food products (e.g. potato and wheat proteins are generally produced as by-products of the isolation of food starches). Although there are significant challenges to extracting protein from these materials, the sheer volume of waste streams makes them attractive targets for further research and development of foods and bio-based materials.

There is significant international competition in the plant protein arena that will make it challenging for New Zealand to make its mark. Similarly, there is significant "trade secret" and patented knowledge of the production of many of the processes. To establish plant protein production industries in New Zealand, we need to use our research capabilities to establish our own "trade secret" processes and protocols for premium plant-based protein foods.

New Zealand has capability in protein research, materials isolation and engineering as well as food product development and sensory science. The main gap in our capability for developing a plant-based protein food industry exists at the larger industrial scale, where equipment/plants suitable for tonne-scale extraction and purification of plant proteins and co-products are limited. In the past, this gap has held back the commercialisation of materials isolation processes developed out of Government-funded science programmes.

The opportunity for New Zealand is in manufacturing high-value plant protein foods, sourcing ingredient streams from trusted sustainable and diversified production systems that meet our future climate change challenges, and delivering premium products into the 'flexitarian' diets of our international customers. For further information please contact:

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1 OPPORTUNITIES TO DIVERSIFY NEW ZEALAND'S PLANT PROTEIN PRODUCTION

Although data from the 2008-2009 New Zealand Adult Nutrition Survey [1] show that plant-based proteins contribute at least 40% of adults' average daily protein intake, New Zealand protein production is currently strongly focused on proteins sourced from dairy (e.g. caseins, whey proteins) and meat. There are significant opportunities for the expansion and development of plant-based protein sources in New Zealand to take advantage of consumer trends towards plant-based foods, plant proteins, and "flexitarian" lifestyles [2]. Crop rotation scenarios with dairy and meat production in New Zealand could result in opportunities to produce new high value-added protein ingredients and functional foods from plants, and deliver on strong sustainable production and diversification drivers across the global food industry.

One of the challenges for plant proteins remains the essential amino acid (EAA) content, which is limited from certain plant sources. This measure is required for exporting and selling protein ingredients almost everywhere except New Zealand. While complementary proteins may be combined to make complete proteins in finished food products, the individual protein ingredients that have a low EAA content are unlikely to achieve a premium. For cereal crops the essential amino acids lysine and tryptophane are limiting, whereas for legumes it is methionine that is the limiting essential amino acid. Improvement of EAA in soy and maize has been achieved through genetic modification to improve lysine content [3], however, use of GM technology to improve EAA content for human consumption limits the suitability of these enhanced crops for New Zealand production.

In deriving a list of plant protein sources known to have been grown in New Zealand, it has to be noted that "high" protein crops are few and far between. For example, potato has a low protein content (based on as-harvested wet weight) but is a high yield crop. Hence considerations such as protein yield per hectare come into play. This is particularly true when considering the protein on a dry matter basis and yield, which are more relevant when determining the protein potential for New Zealand-grown plants. Soy and lupin are probably the two highest protein producers [4] on an as-harvested basis (although perhaps not on a total cost of production basis), but there are challenges to growing these crops in New Zealand, especially soy, which is a (largely) GM crop. Determining a potential protein opportunity must include after-harvest factors, such as processing costs, to deliver a relevant comparison.

Crops that are grown, or have been grown, in New Zealand that could be used as potential sources of protein for human consumption include alfalfa (lucerne), barley, beans (various), canola, hemp, kumara, linseed, lupin, white maize, oats, peas (yellow), peas (green/wrinkled), potato, walnut, and wheat. Anti-nutritional factors (e.g. phytic acid in legumes), potential for toxicity (e.g. potato glycoalkaloids), and/or taste are a consideration in the breeding, growing and processing of many of these crops.

Crops like soy, amaranth, quinoa, millet, sorghum, arrowroot/taro, chia, rice, chick pea, sunflower, sesame, miscellaneous tree nuts, and peanuts are not known to have been farmed in New Zealand. It is highly likely, however, that there are niche locations in New Zealand where the soil, water and climate resources would enable this range of crops, and others, to be grown with productive yields.

1.1 Nutritional qualities of plant proteins

Protein it is a vital component of a healthy diet, and unlike fats and carbohydrates, our body does not store protein. The amino acids within protein are used to build and repair tissues (bones, muscles, cartilage, skin, and blood) and are necessary for the normal growth and development of infants and children. Of the 20 amino acids that our body uses, nine of them are called "essential" because our body cannot make them and they have to come from our diet. Many plant proteins lack one or more of these so-called essential amino acids (EAA) and this is why certain plant proteins are considered "incomplete". Vegetarians work around this by consuming a wide variety of foods to ensure they get a full complement of EAA in their diet.

One of the challenges for individual plant proteins remains their "incomplete" (i.e., may be low in or missing) essential amino acid content. A complete EAA offering is required for exporting and selling protein ingredients almost everywhere except New Zealand. The challenge this brings to plant breeding and protein processing industries has been highlighted in the international science literature [5]. Generally, proteins derived from animal foods (meats, fish, poultry, milk, eggs) are complete, with the only truly "incomplete" animal protein in the food supply being gelatin, which is missing the amino acid tryptophan. Many proteins derived from plant foods (grains, legumes, seeds, and vegetables) are "close to" complete – examples include black beans, black-eyed peas, chickpeas, cashews, cauliflower, kasha, kidney beans, pistachios, potatoes, pumpkin seeds quinoa, and turnip greens. Soy protein is complete, but this was achieved using genetic modification, so growing soy in New Zealand is currently restricted by New Zealand's legislation. Certain traditional dishes, such as Cajun red beans (legumes) and rice, Indian pappu (legumes) and rice or rotta (both Poaceae), Japanese soybeans (legumes) and rice (Poaceae), or Mexican beans (legumes) and corn (Poaceae) combine legumes with grains to provide a meal that is high in all essential amino acids.

The food industry has developed certain standard measures of protein quality, like Protein Digestibility Corrected Amino Acid Score (PDCAAS). Foods that obtain a PDCAAS score of 1.0 (the highest possible score) include certain dairy products (e.g. whey), egg whites, and soy protein isolate. While other foods, such as amaranth, buckwheat, hempseed, meat, poultry, quinoa, *Salvia hispanica*, soybeans, seafood, seaweed, and spirulina are complete protein foods (i.e. contain all the essential amino acids), they may not obtain a PDCAAS score of 1.0 because certain amino acids fall just below the threshold values required for this measure. This limits the financial returns of plant protein ingredient streams.

Plant-based diets can supply "complete" protein to an individual's diet by the practice of "protein combining", which raises the amino acid profile to the equivalent of that of animal proteins. While this approach works when making high-value foods to sell, the ingredients reflect the lower PDCAAS score, which in turn affects the sales price of the ingredients and the potential returns to producers and growers. At this stage, we are not detailing the economic practicality of developing plant protein ingredients, but we will need to remain cognisant of the PDCAAS issue for protein ingredients. We also note that processing may change the amino acid profile of protein. Therefore, it is not always possible to extrapolate the amino acid profile of finished product from that of the raw material.

It is also critical to manage anti-nutritional factors during processing to avoid further concentration. Anti-nutritionals are substances that when present in food reduce the bio-availability of one or more nutrients e.g. trypsin inhibitors and lectins found in legumes. High levels of anti-nutritional factors may adversely affect health.

1.2 Crops with potential to be sources of protein for New Zealand

Several plant crops show significant potential as sources of protein for ingredient and food production in New Zealand.

1.2.1 Alfalfa (Lucerne)

Alfalfa is mostly used as an animal feed in New Zealand (dairy cattle, beef cattle, and deer) and grows very well in the “drier” areas of New Zealand such as Canterbury. The EAA profile of alfalfa is very similar to that of soy and alfalfa protein is attracting interest in the USA and elsewhere. Alfalfa leaves can contain up to 30% protein by weight and the stems up to 10%, making it a high-yielding protein crop. Phytochemicals isolated from alfalfa leaves have been shown in pre-clinical trials to be useful in controlling oestrogen and blood sugar in people, whilst the lipids in alfalfa seeds have been shown to be useful in regulating blood cholesterol, so a 100% utilisation approach is likely to produce high-value materials in addition to the protein.

1.2.2 Amaranth

Although there has been past interest and research on amaranth varieties suitable for New Zealand conditions, amaranth is not grown extensively in New Zealand. Research carried out by the BioPolymer Network (BPN – jointly owned by PFR, AgResearch and Scion), has indicated that amaranth is a source of high-value protein and starch components that could form the basis of a new crop and/or processing industry for New Zealand [6]. Amaranth is also one of the best plant-based sources of squalene, currently derived from marine animals. Amaranth originates from South America but should grow well in New Zealand. Further selection and or development in breeding programmes may be required to optimise it for New Zealand conditions.

1.2.3 Cereals

Cereals such as barley, wheat, rye and oats are grown primarily for production of cereal-based foods for human consumption, as feedstock for the brewing industry, or for animal feed. Although cereals contain lower amounts of protein than legumes, they have quite different functionality because of their high glutamine content and lower solubility. Wheat protein (gluten) production is a major global industry. Spent grain by-product streams from brewing, and wheat bran from milling, represent significant sources of protein (19-30% w/w) and fibre (30-50% w/w) that could be utilised in New Zealand [7]. Internationally, the opportunity may lie in utilising the water-soluble proteins from the wash water during gluten manufacture. However, these may also contain water-soluble anti-nutritional compounds such as amylase trypsin inhibitors. PFR has Plant Variety Rights over a number of the key varieties of cereals used in New Zealand and has an active breeding programmes for the key cereal crops. Our research suggests there would be no major commercial advantage in using varietal differences (e.g. strong wheats versus weaker wheats) to differentiate gluten types and functionality.

1.2.4 Kiwifruit seeds

Kiwifruit seeds are a by-product from juicing/pulping of second-grade fruit and are either composted or used as a source for extraction of polyphenolic compounds and oils for various nutraceutical and personal care products (e.g. New Zealand Extracts, Oilseed Extraction Ltd). Kiwifruit seeds also contain protein and beneficial fibre so are potential candidates for protein, although the amino acid profile of the proteins has not been investigated.

1.2.5 Oilseeds

Seeds such as canola and linseed are grown for their high-value edible or industrial oils and their processing results in the production of a by-product stream of “seed cake” that is rich in protein. However, the seed cake contains large amounts of anti-nutritional compounds that are an impediment to isolating a functional protein product. It is likely that a substantial investment would have to be made in technology to address this aspect. Oil seeds are bred to maximise the yield of edible oil from the seed crop. There may still be opportunities to breed for an improved protein component at the same time, or to optimise processing to improve protein quality in the seed.

1.3 Sustainable production considerations for New Zealand protein sources

There is a great deal of research and media commentary indicating that meat and dairy production are reaching their limits in New Zealand with respect to sustainability, and that diversification of cropping systems is required to ensure sustainable economic development into the future. Furthermore, should there eventuate, as is likely, a tax on carbon emissions, the profitability of livestock farming will assuredly decline. Meanwhile, because of the low greenhouse gas emissions from plant-based food production systems, their profitability will be less affected. On an areal basis, the EBIT per hectare of horticulture exceeds those of livestock and dairy farming.

New Zealand has topographically challenging landscapes (e.g. hill country) that may continue to be valid for use of livestock to assimilate material from large areas. However, there are also potential opportunities to exploit many niche locations for high-value protein production (see Section 1.4). The water and nitrogen footprints of plant-based food production are many times less than those of livestock farming. Furthermore, the nutrient ‘leakiness’ of annual, or perennial, plant production systems is low, given the absence of grazing animals. Consideration of the circular economy [8] will ensure shifting from animal to plant based proteins does not deliver any unintended consequences (e.g. pollution swapping).

Crop plants provide a diversity of options for land-based protein production for New Zealand. Production of protein via an animal eating plant-based feeds that contain protein is argued to be inherently very inefficient. Crops that require fewer chemical (e.g. fertiliser) or water inputs than dairy or meat can be integrated into crop rotations to reduce the overall environmental impact of the annual land use cycle. For example, crops such as peas, fix nitrogen and therefore lead to greatly reduced fertiliser requirements over the annual land use cycle. Crops like amaranth are inherently suited to drier regions and organic production systems. The development of nut tree cropping can also assist in land stabilisation in areas that have previously been overgrazed and have become prone to erosion.

1.4 Potential for diversified cropping to support plant protein production in New Zealand

New Zealand is a primary-production nation, with 65% of its export revenues coming from agriculture, horticulture and forestry. This success is underpinned by public and private investment into R&D and innovation. New Zealand can invest human, financial and institutional capital to gain value from primary production. Furthermore, New Zealand is blessed with natural capital assets: soil resources, water availability (albeit under pressure), niche microclimates, and clean air. From these natural capital stocks flow valuable ecosystem services. From just 140,000 ha, horticulture produces $8 billion of value [9]. This 140,000 ha is just a small fraction of the area within New Zealand that could be used for horticulture, or could be used for high-value protein production.

It is possible to estimate the most suitable lands and climate to support plant production for high-value protein foods. Firstly, this would be limited to versatile lands that come under Land Use Capability (LUC) Classes 1-3. Next, for ease of management and harvesting lands should be at a slope of less than 5º. In terms of climate, there should be at least a growing degree day (GDD) accumulation of 800 (base 10°C), and a frost-free period of greater than 180 days. Using these criteria in a Geographic Information Systems (GIS) scan of New Zealand, generates the map in Figure 1.

As a rough estimate, New Zealand has more than 1,737,000 ha of land suitable for growing plant protein crops. This is more than 10 times the land area currently contributing to the horticulture industry's $8 billion. Our land and climate resources offer many plant food opportunities for New Zealand that have valuable returns with low environmental footprints.

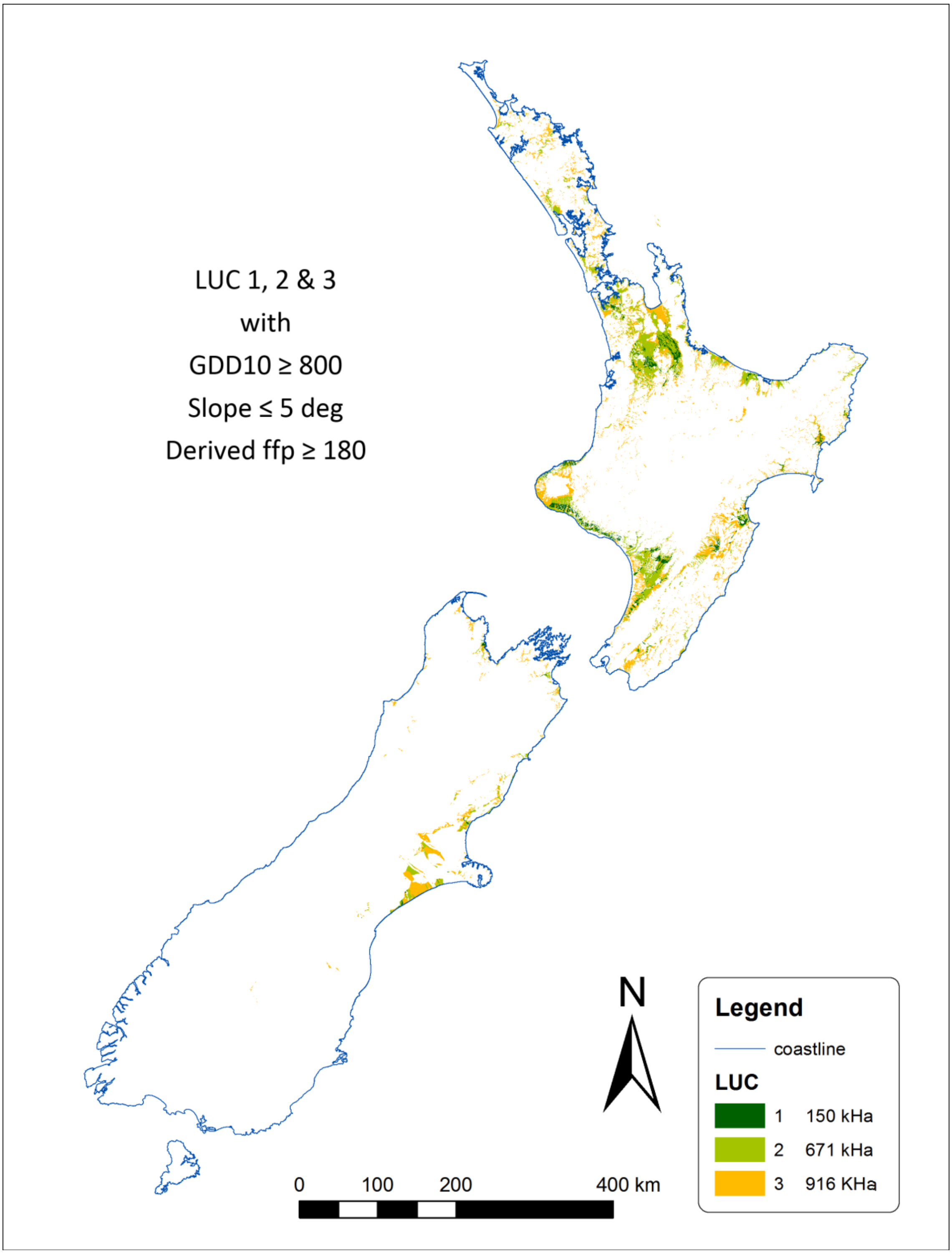

Figure 1. Geographic Information Systems (GIS) scan of New Zealand, indicating most suitable lands and climate to support plant production for high value protein foods. LUC = land use capability; GDD = growing degree day; ffp = frost-free period.

1.5 New Zealand's ingredient manufacturing capabilities

The majority of plant proteins used in the New Zealand food industry are manufactured overseas (e.g. gluten in Australia/Europe, yellow pea protein in Canada/Europe). Many of the requirements for isolating and manufacturing plant proteins are similar to those for dairy proteins. It is likely that engineering expertise and manufacturing capability from the dairy industry could be applied to manufacturing plant proteins. The main issue around this approach is the willingness of the dairy sector equipment suppliers to provide pilot-scale equipment of sufficient size to develop the ingredients.

One option would be to work with the New Zealand Food Innovation Network to explore the role of one or more of its member sites becoming a plant protein centre of excellence. Using this network's input and expertise, New Zealand could evolve its plant-based protein manufacturing to a semi-commercial scale, as has been the case already for dairy food innovation at FOODWaikato. Existing infrastructure, however, is not ideally located where the majority of our plant crops are likely to be grown. Geographic location and proximity to production is necessary to limit degradation of plant material destined for processing, reduce the need for postharvest storage pre-treatments (e.g. drying), and reduce transportation requirements from farm to factory. The potential value of plant-based proteins is strengthening business cases for investing in plant food innovation infrastructure. For example, Roquette have recently made significant investment (>€300M) in dedicated pea protein processing facilities in Canada and Europe on the back of high world demand for pea protein.

Research carried out by PFR in the Government-funded Lifestyle Foods programme (2004-2010) demonstrated that protein, starch and fibre from wrinkled peas could be isolated on a tonne scale (raw material) using readily available industrial-scale equipment. Typically, the protein isolation methods are adapted from those published in the open literature, so similar methods can be applied to isolate proteins from a number of plant material sources. This process could be up-scaled but would require a significant capital investment. Commercial work led by PFR's Food Solutions team has also shown New Zealand's capability to develop protein ingredients by processing > 20 MT at pilot-plant scale.

1.6 A focus on premium plant-based foods

Thus far, functional plant proteins with nutritional attributes continue to meet specific market needs and have avoided becoming commoditised. The prices for functional plant proteins as ingredients (e.g. pea protein and potato protein) remain high because of worldwide shortages. The high demand for plant proteins is driven by their use in new product development (NPD) in the developing vegetarian/vegan food sector, as well as in non-meat and non-dairy foods for the general population. Although significant NPD has occurred to date, many of the plant protein foods are still of lower sensory quality than their dairy-based equivalents. There remains a significant opportunity to develop new food technologies and functionalities for plant protein foods that better meet consumer expectations.

Companies such as Impossible Foods and Beyond Meat have captured IP in the meat replacement area, yet opportunities still exist to produce foods such as dairy alternatives and meat analogues that have higher consumer acceptance and provide a nutritionally equivalent product to animal-derived products. For example, soy milk provides an acceptable nutritional alternative to cow milk but has a distinct flavour considered undesirable by some consumers. Within New Zealand a number of start-up companies are pursuing meat analogues. Sunfed Meats is an Auckland-based company producing "chicken chunks" made from pea protein that fry and crisp up just like chicken. Angel Food is active in producing both the meat-and cheese-alternatives. Bean Supreme has been active in the plant-based products since 1984, producing tofu and meat alternatives sold in New Zealand and Australia.

The opportunity for New Zealand is in manufacturing high-value plant protein foods and sourcing ingredient streams from sustainable and diversified primary production systems. New Zealand's food industry, together with the established research partners and the Food Innovation Network's pilot-scale infrastructure [10], can contribute to this space through expertise in NPD in food and beverage, availability of scale-up equipment, application of novel protein chemistry in the formation of food protein structure, and evaluation of sensory quality of manufactured food structures, as well as in the development of new processes to manufacture these foods and beverages.

1.7 'Whole of plant' utilisation

Isolation of proteins from plant sources is most economical when the whole plant is used; that is, when the protein is one of a number of product streams isolated during the manufacturing process. For example, wheat gluten protein is actually a by-product of a simple washing process to isolate wheat starch. Similarly, pea protein is isolated from pea flour using isoelectric precipitation prior to isolation of the starch, so that close to 100% of the harvested pea seed is utilised.

Many of the materials that could be utilised to produce plant proteins are so-called "by-products" or "waste streams" from production of other food products. Oil seeds such as canola are usually cold-pressed to extract the valuable edible oils that they contain. The "waste" material is high in protein and fibre and is usually sold for use in animal feed or simply composted. Although there are significant challenges to extracting the protein from these materials so that it is free of any anti-nutritional materials, the sheer volume of these waste streams makes them attractive targets for further research and development of foods and bio-based materials.

New Zealand has led this type of thinking on total utilisation, starting with the "waste stream" of whey in the 1970s, which is now one of the most profitable dairy protein ingredients worldwide. We are in a position to use the same approach with our crop plants, achieving high-value streams of protein, starch, fibre and other important components from a single bioresource.

A "whole of plant" utilisation approach for New Zealand may lead to unique plant protein opportunities because it will make certain plant protein opportunities viable. This approach means that a business case for a novel plant protein and its food uses should also consider how the other plant fractions (once protein extraction is completed) might be utilised, and this could extend beyond foods uses into biomaterials and biocomposites. For example, extraction of protein from garden peas might result in a food-grade starch by-product as well as an insoluble fibre that could be used as a prebiotic food ingredient or a biomaterial for reinforcing bioplastics (made possible because it is an elongated fibre). Similarly, extraction of protein from oilseeds might also produce a highly fibrous by-product that could have food and/or biomaterials uses. The other untapped opportunities for producing plant proteins are from waste streams of more profitable ingredients, e.g. canola oil, where recovering the protein adds profit to an already profitable food. The protein ingredient, therefore, does not have to carry the cost of the total process. This total utilisation approach is the generally accepted international model for ingredient manufacture profitability.

2 CHALLENGES TO DIVERSIFYING NEW ZEALAND'S PROTEIN PRODUCTION

2.1 Global competition

There is significant international competition in the plant protein arena that will make it challenging for New Zealand to make its mark. Although many of the methods for isolating and extracting plant proteins are freely available through the published literature, rarely are those processes followed in the industry because of the lack of relevant heating and process flow rates. There is also significant "trade secret" and patented knowledge of the production of many of the processes. To establish plant protein production industries in New Zealand, the challenge, and opportunity, is to use New Zealand's research capabilities to establish our own "trade secret" processes and protocols.

Similarly, many of the chemical and physical processes for transforming plant proteins into functional foods may, at first glance, appear to have been captured by overseas companies – Impossible Foods being a primary holder of many patents in this area. However, the sensory quality of plant protein-based foods (such as dairy analogues) is still limiting their performance in comparison to animal-based alternatives. Hence there is still significant scope for New Zealand's food industry to develop value-added plant protein-based foods with higher consumer acceptability, particularly outside the niche vegan and vegetarian markets, where many of the current products are aimed.

2.2 Capability and infrastructure

We have significant capability in protein science, materials isolation and engineering of plant foods, and we have significant food product development and sensory science capability. This will allow us to carry out protein isolation work at laboratory-, pilot- and small industrial-scale, and allow for NPD work to formulate high-value consumer food products.

The main "gap" in New Zealand's capability, however, exists at the larger industrial scale, where equipment/plant suitable for tonne-scale extraction and purification of plant proteins and co-products needs to be extended, potentially emulating the FOODWaikato model for drying. In the past, this gap has held back the commercialisation of material isolation processes developed out of Government-funded science programmes. FOODPilot at Massey is moving in that direction, particularly with the expansion to include AgResearch pilot-plant facilities attached to FOODPilot. Expanding FOODPilot further to include the additional equipment needed for plant protein ingredients is an obvious next step.

3 COMPONENTS OF A NEW ZEALAND PLANT-BASED PROTEIN INDUSTRY

Our future food system will be a complex network of activity. For simplicity, we have taken a supply chain view of the likely components required by the New Zealand industry to diversify our premium protein offerings successfully (Figure 2). Here, we have identified the areas where knowledge, capability and technology will add to our success.

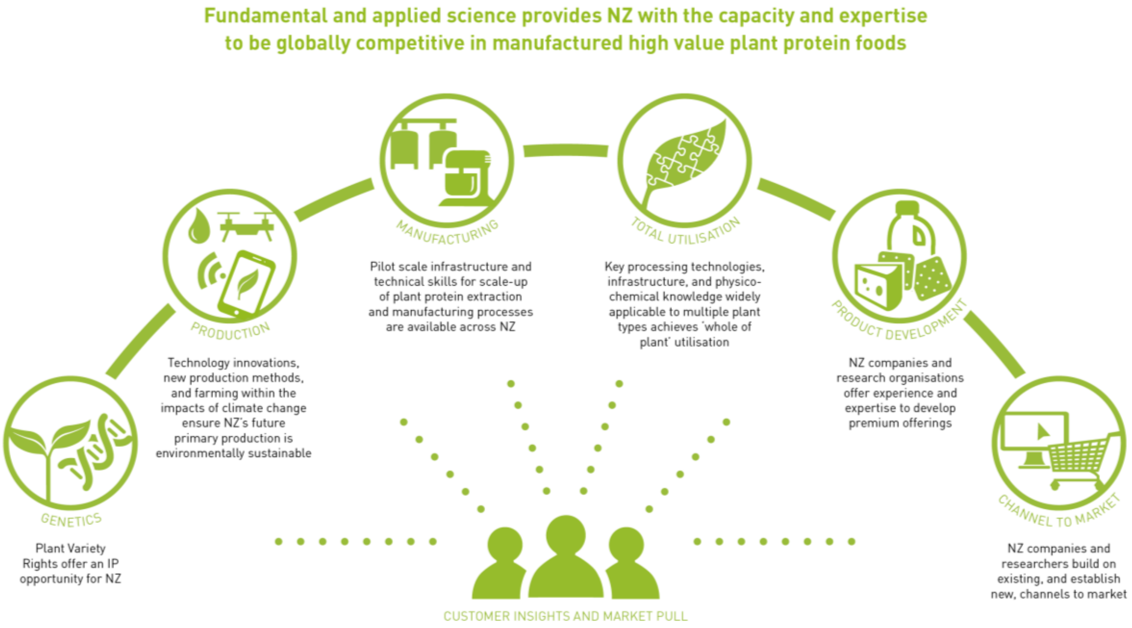

Figure 2. The path to a premium plant protein food market.

3.1 Genetics

'Plant Variety Rights' offer an IP opportunity for New Zealand.

- Development of new PVR-protected cultivars with enhanced protein functionality, composition or concentrations that make them suitable as raw materials for protein isolation and will secure a competitive advantage
- Opportunity for new PVR-protected cultivars with decreased concentrations of anti-nutritive and off-flavour components will simplify processing and make it more cost effective
- Taking advantage of genetics that impart favourable properties to the major non-protein components (e.g. starches and oils) would enhance the viability and economics of crop production by enabling total utilisation of the plant bioresource
- Developing cultivars that confer unique functional properties (processing and/or nutritional) when the whole plant material is used to create a value-added food or beverage products
- Identifying crops and cultivars fit for future sustainable production scenarios and climate change (e.g. need less water or capable of growing in wetter conditions, need fewer fertiliser inputs, have insect and pathogen resistance).

3.2 Production

Technology innovations, new production methods and farming within the impacts of climate change, ensure NZ's future primary production is environmentally sustainable.

- Generating new knowledge about agronomic practices to maximise protein yield and protein functionality, and to understand the effects of yield, and agronomic practices on protein attributes
- Developing sustainable, low-input practices to maximise environmentally robust production for ingredients, foods and materials
- Reducing environmental footprints by designing crop rotations that complement animal production
- Adapting production of crops (and their downstream products) to suit future regional climate scenarios
- Exploring non-farm technologies (e.g. fermentation) for production of plant-based foods.

3.3 Manufacturing and infrastructure

Pilot scale infrastructure and technical skills for scale-up of plant protein extraction and manufacturing processes is available across New Zealand.

- Identifying critical technology infrastructure required to enable New Zealand to participate in plant-based protein production
- Cataloguing the knowledge skill base in New Zealand research institutions and companies related to understanding proteins from first principles to commercial products. While much of the experience is in dairy and meat proteins, the protein physico-chemical fundamentals translate into all proteins
- Establishing a network of processing and manufacturing infrastructure aligned with distribution of crop production. This requirement is particularly important when it comes to the need for minimal degradation of plant material destined for processing so that yields and functionality are not diminished prior to processing, and the needs for secondary processing (e.g. drying), transportation and storage are minimised.

3.4 Total utilisation

Key processing technologies, infrastructure and physico-chemical knowledge widely applicable to multiple plant types are available and enable whole-plant utilisation.

- Extending protein, polysaccharide (starch/fibre), carbohydrate, mineral and lipids extraction and isolation to commercial scale
- Manipulating existing processing capabilities to manage protein and other component functionality for application to foods and for specific nutritional targets

- Developing expertise of protein structure through physical, chemical and/or enzymatic technologies
- Developing storage and logistics protocols to maintain food safety of materials, especially by-product streams
- Developing treatment technologies for any final waste materials that minimise environmental impacts
- Developing processing technologies to convert non-food suitable materials into valuable bio-based materials (e.g. electrospinning applications)
- Developing process, product and cost modelling for physical, chemical and functional attributes of the ingredients and the targeted food applications
- Creating total value-chain management of the process from the farm to the final customers.

3.5 New product development

New Zealand companies and research organisations have experience and expertise to develop premium offerings.

- Building understanding of the complex interactions between proteins and other ingredients in formulations and during food processing
- Enhancing expertise in targeting foods for sensory experience relevant to different cultures and markets
- Enhancing expertise in the development of protein structure through physical, chemical and/or enzymatic technologies
- Developing expertise in the use of by-product streams (e.g. carbohydrates) for value-added products
- Developing expertise in fermentation technologies for the development of value-add plant foods with targeted sensory and nutritional properties (especially for the Asian market)
- Developing storage and logistics to maintain food safety in processing and in the supply chain.

3.6 Research and development

Fundamental and applied science provides New Zealand with the capacity and expertise to be globally competitive in manufactured high value plant protein foods.

- Understanding the impact of tertiary conformation of proteins on processing, with a focus on physical, sensory and nutritional characteristics of the proteins necessary for targeted food applications
- Enhancing knowledge of how to manipulate essential and non-essential amino acid compositions through breeding and processing relevant for market access (food standards) as well as functionality and nutrition
- Understanding the bioprocessing engineering principles and costs to optimise yields and maximise use of all the plant component streams

- Enhancing knowledge of protein structure, cross-linking chemistry, and instrumental methods for quantitatively determining effects of structure development (e.g. rheology, mass spectrometry)
- Enhancing knowledge of protein structure effects on human oral processing and perception of food texture
- Understanding effects of modification of protein structures on digestion processes and related human health outcomes (e.g. satiety, allergenicity)
- Using chemistry knowledge to engineer the genetic control of protein synthesis and enhance germplasm supply.

3.7 Consumer Insights and Market Pull

Consumer understanding must be woven into each step on the path to premium plant based foods so that we may better understand the potential shifts in behaviour and attitudes towards future foods.

"That consumer will eat more plant protein in the future is inevitable. The question is: will this protein be processed to look and taste like meat? I believe ***consumers will adopt plant protein but in an authentic way that allows it to be recognised as plant protein*** *rather than mock meat!*

There is an opportunity for food science to create and modify plant protein to deliver ***greater diversity of texture, taste and flavour.***

There is an opportunity for nutritional science to create and modify plant protein-based foods in a way that provides ***better overall nutrition.***

There will be a large group of consumers who will respond very positively to the plant protein-based foods that deliver sensory and nutritional value. There has been little if any research to ***identify what the specific needs of these consumers will be."***

Dr Roger Harker, April 2018

4 CONCLUSIONS

If we stand back and look at New Zealand, we can see production capability, a knowledge of food, and a good understanding of our export markets and their differentiating factors. The underlying trend in plant-based protein is clear: consumers are opening their eyes to plant-based foods with a focus on proteins, and marketers are responding. We do not believe there is an option for New Zealand to simply do nothing, and increasing the diversity across New Zealand's protein-based value chain will create resilience for our food economy. However, we must recognise that the whole of our primary sector might choose not to respond.

Beyond the 'hype cycle' of plant-based proteins there are four things we should be cognisant of as we develop a strategy to meet the plant-based protein challenge:

- Maintain and build on our reputation as a producer of high-value natural foods
- Leverage our longstanding advantage as dairy food and beverage innovators
- Adapt our production systems to cater for the future challenges and facilitate resilience at the grassroots level
- Keep monitoring to increase awareness of markets.

5 REFERENCES

[1] Health NMo 2009. 2008-2009 New Zealand Adult Nutrition Survey.

[2] J M 2017. 10 Key Trends in Food, Nutrition and Health, 2017. http://www.new-nutrition.com/report/showReport/1540

[3] Ufaz S, Galili G 2008. Improving the content of essential amino acids in crop plants: goals and opportunities. Plant Physiology 147:954-961. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2442549/.

[4] Day L 2013. Proteins from land plants – Potential resources for human nutrition and food security. Trends in Food Science & Technology 32(1): 25-42.

[5] Ufaz S, Galili G 2008. Improving the Content of Essential Amino Acids in Crop Plants: Goals and Opportunities. Plant Physiol 147(3): 954-961.

[6] Amaranth Starch and Protein product specifications - Biopolymer Network
http://www.biopolymernetwork.com/content/Amaranth-Starch/40.aspx
http://www.biopolymernetwork.com/content/Amaranth-Protein-P1/53.aspx
http://www.biopolymernetwork.com/content/Amaranth-Protein-P2/54.aspx

[7] Lynch KM, Steffen EJ, Arendt EK 2016. Brewers' spent grain: a review with an emphasis on food and health. Journal of the Institute of Brewing 122(4): 553-568.

[8] https://www.ellenmacarthurfoundation.org/circular-economy

[9] FreshFacts, New Zealand Horticulture 2016. http://www.freshfacts.co.nz/

[10] Food Innovation network http://foodinnovationnetwork.co.nz/.

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