Protein For Life – Work Package 4; Industry Report

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1. Introduction

Food is central to every aspect of our lives. It provides not only nourishment, but also influences our social interactions, health and well-being. Today we are living longer than ever before and the importance of healthy ageing is increasingly recognised. The challenge for the Protein For Life project is to develop and maintain a healthy protein intake in the ageing population to support healthy ageing.

Work Package 4 of the Protein For Life project aims to develop a set of design rules for the formulation of palatable and sustainable high-protein foods. This report discusses the industry-based challenges that are specific to product design constraints relating to palatability, functionality, and cost. Eleven semi-structured telephone interviews were conducted with food industry partners. The interviews were designed to gain in-depth views around primary topics identified at the project launch, and to identify new topics and emerging themes. The report was also supported by the analysis of a broad range of scientific papers, industry reports and national statistics. Findings from the analysis were presented and discussed with food industry partners at stages throughout the study and the final key points are summarised below.

2. Key points

- **Cost** is the main limiting factor for product development, and this is significantly impacted by raw ingredient cost and by ingredient functionality.
- **Favouring plant-based proteins over animal proteins,** due to their greater environmental sustainability, could make development of high protein products difficult due to the lower protein content of plant proteins relative to animal proteins. Protein fractions are an obvious solution however they are not suitable for use in all product segments and can be associated with higher costs.
- **The industry perceived protein quantity** to be of higher value than protein quality for the consumer, due to the lack of consumer awareness about the role of protein in age-related muscle loss, and the lack of an appropriate health claim to support increased consumer awareness.
- Although recognised as an issue for protein fractions specifically, **palatability** was not regarded as a major barrier for product development, due to advances in research and development, and supportive ingredient suppliers.
- **A reliable and scalable supply chain** for raw protein ingredients was regarded as an essential consideration both for small and large manufacturers.
- **Lack of consumer awareness** was identified as the main non-manufacturing barrier to the development of age-related high-protein products; the industry would welcome greater involvement from public health bodies to create a clear and concise health message for consumers
- **Consumer acceptance** of 'functional' protein products could be a barrier to product success; to increase consumer acceptance, further research into consumer attitudes and behaviours is required – this will help develop an effective **marketing approach** for age-related high-protein products
- Although there was agreement that the current protein **labelling requirements** were appropriate for the UK market, an age-related protein nutrition claim could significantly aid product marketing and ultimately determine the success of a product
- **The industry is proactive, well equipped, and will be highly successful** at overcoming the recognised and emerging formulation challenges specific to plant-based protein ingredients

3. Factors driving plant-based proteins

Age-related muscle loss, or sarcopenia, is a natural symptom of ageing. It is estimated that over the age of 40 years, muscle mass decreases by approximately 8% per decade, increasing to 15% per decade over the age of 70 years [1,2]. Factors that contribute to this muscle loss include hormonal changes, altered inflammatory and immune responses, changes to protein synthesis, decreased physical activity and reduced calorie and protein intake [3]. Consequently, in comparison with younger adults, older adults eat more slowly, they are less hungry and thirsty, consume smaller meals, and fewer snacks - food intake can fall by as much as 25% between 40 and 70 years of age [4]. Along with physical activity, evidence suggests that protein intake above the current recommended daily intake (RDI) of 0.75g/kg bodyweight for adults can slow the onset and severity of sarcopenia [5,6]. Studies have demonstrated that the most effective quantity and spacing of protein intake throughout the day is a total of 1.0-1.2g/kg bodyweight ingested at a minimum of 25-30g per meal or eating occasion [7–9]. In the UK, the majority of adults obtain a large proportion of their daily protein intake during their evening meal [10]. Ensuring a protein intake of 30g at each meal/eating occasion throughout the day (breakfast, lunch, dinner, snacks) would not only optimise muscle synthesis but also allow older adults to achieve the higher recommended protein intake of 1.0-1.2g/kg (80-96g per day for a person weighing 80kg).

The human body is able to produce most of the amino acids required to synthesise protein, however there are 9 amino acids which can only be obtained from our diet. These are termed the essential amino acids (EAAs). In Western cultures, protein needs are largely obtained from animal sources including meat, seafood and dairy. The most convenient solution would be to encourage increased consumption of readily available animal proteins, as they are nutritionally dense, they contain all EAAs, they are readily availability in the food industry supply chain, and have wide consumer acceptance. Unfortunately reliance on animal proteins is environmentally unsustainable under current production methods, is contributing to climate change and is unlikely to be able to meet the food needs of the predicted increase in global population. Ruminant meats (beef and lamb) can have greenhouse gas emissions per gram of protein that are as much as 250 times those of legumes[11]. Consumption of limited amounts of animal protein may be environmentally sustainable under the correct production methods however such a model would rely on a significant increase in consumption of plant-based foods. A growing number of epidemiological studies have shown that replacing animal protein with plant protein is associated with lower mortality [12]. While it is unknown to what extent the numerous non-protein components of plant foods (fibre and phytonutrients) and animal foods (saturated fat) are involved in healthy ageing, consumers have reacted by reducing their consumption of red meat. A survey released in August 2017 reported that over a quarter (28%) of UK consumers have reduced or have limited their meat consumption in the last six months and a further one in seven (14%) said they were interested in limiting or reducing their consumption of meat or poultry in the future [13]. Although UK consumption of meat is in a steady and consistent decline, the overall intake of protein from all sources is well over Public Health England's recommended 12% of the total energy intake per day [14]. Animal-based proteins (meat, seafood, dairy and eggs) are the greatest contributors.

A greater focus on increasing the consumption of plant proteins is in line with government health recommendations to increase intake of fruit, vegetables, pulses and legumes. Consequently, economists, environmentalists and nutritionists are focused on plant-based diets and plant-derived protein ingredients.

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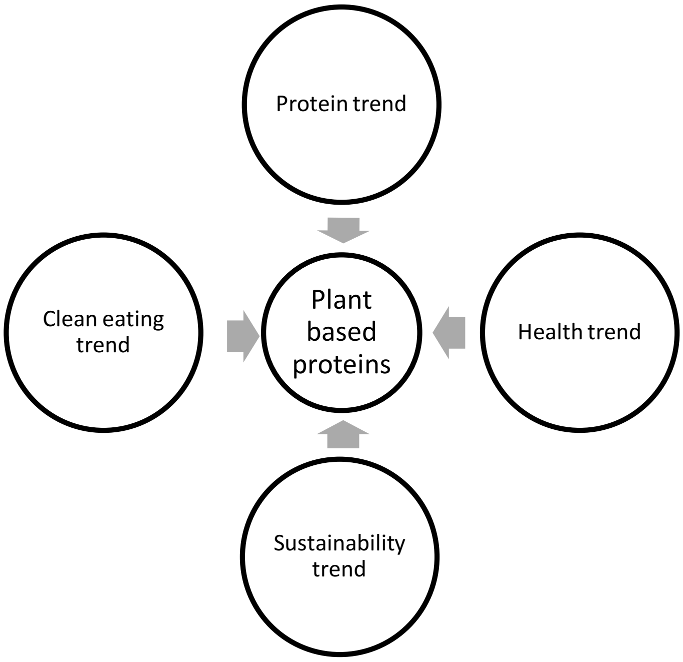
4. Protein Trends in the Food Industry

The global plant protein market is expected to grow at a compound annual growth rate (CAGR) of 8.29% between 2017 and 2021 [15]. There are a number of consumer trends that are driving demand for plant-based protein sources, as illustrated in Figure 1.

Figure 1: Trends driving plant-based protein developments



The global demand for animal-based proteins is predicted to grow by as much as 95% increasing the global share of animal-based calories from 18% in 2010 to 23% in 2050 [16]. This is due to an increasing global population, emerging economies, increasing urbanisation and the recognition of protein's role in a healthy diet.

In the UK, consumer interest in protein as a health trend has traditionally been driven by the fitness industry, where protein was used for muscle building and is provided in the form of functional products including protein shakes and bars, typically for the younger adult. More recent links to satiety and the popularity of low-carbohydrate diet plans have encouraged the use of protein as a weight management aid. That, coupled with the recognition of the importance of protein for healthy ageing, has positioned protein around a more mainstream audience that includes health-conscious consumers of all ages.

Running parallel to this health trend is the desire for products that are both environmentally sustainable and ethically sourced. Growing awareness of the negative effects of animal production is driving demand for plant-based products and the rise of the flexitarian consumer. Veganism is on the rise (up 360% in the UK between 2006 and 2016 [17]) and the trend for 'free-from' and 'allergen-free' products which traditionally met the needs of vegan and vegetarian consumers has expanded into the mainstream. Alongside this is the 'Clean Eating' trend, which sees consumers seeking out 'natural' unprocessed whole foods perceived to be healthier (often regardless of the evidence base).

The industry has responded to these trends, as evidenced by the huge availability of plant-based sport nutrition, plant-based ready-meals and chilled 'to-go- foods, dairy-free plant-based drinks, and exciting and novel meat replacements. There has been less interest in the potential of the healthy ageing market though, which may represent an untapped goldmine. The proportion of adults aged 65 years and over in the UK in 2016 was 18% which is predicted to increase to 24.7% by 2046 [18]. Regardless of the growing consumer pool, the healthy ageing sector is something of a conundrum in terms of product development. There is confusion regarding the appropriate intake and source of protein for the older adult, and reluctance to develop the right marketing angle required for this under-researched demographic. The anti-ageing skincare industry is a prime example of how innovative product development and sensitive marketing can attract the older adult, however the same tactics cannot be applied to the food industry due to the moral obligation to provide evidence-based health messages and the labelling restrictions that are in place to uphold them. This is where the food industry can play a central role, by creating innovative products that allow consumers to balance their desire for taste and convenience whilst meeting nutritional recommendations essential for optimum healthy ageing. The salt reduction policy is a great example of how collaboration between government, public health, academia and the industry can alter consumer eating habits for the better.

5. Current protein uses in the food industry

Protein as a food ingredient can be simply considered as existing in two basic forms; 1) a whole food ingredient with high protein content, for example a nut (almond), seed (pumpkin seed), grain (rice), legume (pea), algae or fungi, and, 2) an extruded protein fraction, available as a concentrate, isolate or flour. Protein fractions can further be processed into textured vegetable proteins (TVPs) by force extrusion, steam injection, jet cooking or acid-salt coagulation. The end result is a product with a defined texture, appearance and functionality.

Table 1 lists some of the current and emerging plant protein sources and their notable characteristics however the research and available information on these sources is extensive and cannot be covered in the scope of this report. For detailed descriptions of plant protein sources and their characteristics, refer to *Sustainable Protein Sources* [19].

Table 1: Current and Emerging Protein Sources

Protein source	Notable characteristics
LEGUME • **Soybean** • **Peanut** • **Pea** • **Lupine** • **Chickpea** • **Cowpea** • **Faba bean** • **Lentil** • **Black bean** • **Mung bean** • **Kidney bean**	Of the legumes, only soybean is a complete protein, containing all the essential amino acids. Protein content ranges from 20-40%. Excellent functionality (soy) and potential for many applications (e.g. textured soy proteins). PROS: low allergenicity (exceptions are soybean, peanut and lupine), gluten-free. CONS: anti-nutritional factors, low digestibility and palatability can be a challenge with legumes.
GRAIN • **Wheat** • **Spelt** • **Quinoa** • **Amaranth** • **Rice** • **Oat** • **Sorghum** • **Millet**	Of the grains, only quinoa is a complete protein, containing all the essential amino acids. PROS: low allergenicity (apart from wheat), recognised consumer acceptance CONS: low protein content
NUT/SEED **Tree nuts:** • **Almond** • **Brazil nut** • **Walnut** • **Hazelnut** • **Cashew** **Seeds:** • **Sunflower** • **Pumpkin** • **Flax** • **Hemp** • **Canola**	PROS: good application for snack bars, cereals, wide consumer acceptance CONS: Allergenicity is an issue for the tree nuts, high energy density may be an issue.
PLANT/FUNGI • **Potato** • **Duckweed** • **Mankai** • **Mycoprotein** **Seaweed:** • **Nori** • **Wakame** • **Kombu** • **Dulse** • **Carrageen** **Microalgae:** • **Spirulina** • **Arthrospira** • **Chlorella** • **Dunaliella**	Algaes have the lowest carbon, water and arable land footprints of any crop [20]. Arthrospira and Chlorella spps. are complete proteins; containing all the essential amino acids. Protein content ranges from 45% (Duckweed) – 70% (Microalgae). PROS: Seaweeds are a good source of Omega 3s, low allergenicity, good palatability. CONS: Limited application of algae (typically fortification/functional foods)

Functional ingredients

When developing a new product or reformulating an existing one, a raw ingredient's functional properties are assessed by the food industry to determine its suitability. The functionality of food proteins can be defined as "any physico-chemical property which affects the processing and behaviour of protein in food systems, as judged by the quality attributes of the final product" [21]. These physico-chemical properties will determine the functionality during manufacture (blendability and ease of incorporation into the food matrix), palatability of the end product (e.g. flavour, texture, aroma, appearance, mouth-feel), and ultimately the final production cost. Nutritional quality can also dictate a protein's functionality, as protein content, amino acid profile, digestibility, and bioavailability become increasing essential constraints in product design briefs.

Knowledge of the physico-chemical properties of a protein ingredient allow for a higher degree of precision when formulating a product as they determine the ability of the ingredient to gel, foam, blend, dissolve, bind, thicken or emulsify in a food matrix, as illustrated in Table 2. These attributes of protein ingredients are typically listed by raw ingredient suppliers to provide indications of use for the food manufacturer. Achieving a balance between functional attributes in a formulation – often referred to as 'the sweet spot' is essential for creating a product that the consumer will accept and enjoy, as shown in Figure 1.

Table 2: Functional properties of proteins, adapted from *Sustainable Protein Sources*[19]

Functional Property	Mechanism and Physicochemical Property of Protein	Example Food System	Example Protein	Sensory Property
Solubility	Hydrophilicity, charge and ionisation of surface residues, H-bonding	Milk, protein-rich beverages, non-dairy milks	Dairy, soy, almond, rice	Flavour, taste, mouthfeel, turbidity
Viscosity	Hydrodynamic size and shape, H-bonding	Soups, gravies, salad dressings, desserts	Gelatin, soy, egg	Taste, consistency, mouthfeel
Water binding	H-bonding, ionic hydration	Comminuted meats, low-fat meat products, bakery products	Muscle, egg, cereal, soy	Texture, consistency
Gelation (heat-induced)	Water entrapment and immobilisation, network formation, thermal aggregation	Emulsified meat products, bakery products, puddings	Muscle, egg, dairy, seed proteins	Mouthfeel, texture, grittiness, smoothness
Cohesion and adhesion	Hydrophic-, ionic- and H-bonding	Emulsified meats, pasta and noodles, bakery products,	Muscle, egg, dairy, seed proteins	Stickiness, chewiness, particulate

		extruded snacks		
Elasticity	Hydrophobic bonding, disulfide cross-linking	Meat products, leavened bakery products, extruded products	Muscle, gluten proteins, casein	Texture, crispiness, chewiness
Emulsification	Adsorption and film formation in oil-water interface, hydrophobicity, hydrophilicity	Comminuted meats, cakes, soups, salad dressings, nondairy milks, desserts	Muscle, egg, dairy, seed proteins, rice bran protein	Mouthfeel, flavour, smoothness
Foaming	Adsorption and film formation in air-water interface, hydrophobicity, hydrophilicity	Icecream, cakes, whipped toppings, mousses, desserts	Dairy, egg, seed proteins, wheat protein	Mouthfeel, smoothness, frizziness
Fat and Flavour binding	Hydrophobic bonding, entrapment	Flavoured milks, protein-rich beverages, emulsified meats, bakery products, sauces and gravies	Dairy, egg, muscle, many seed proteins	Flavour, odor, smoothness

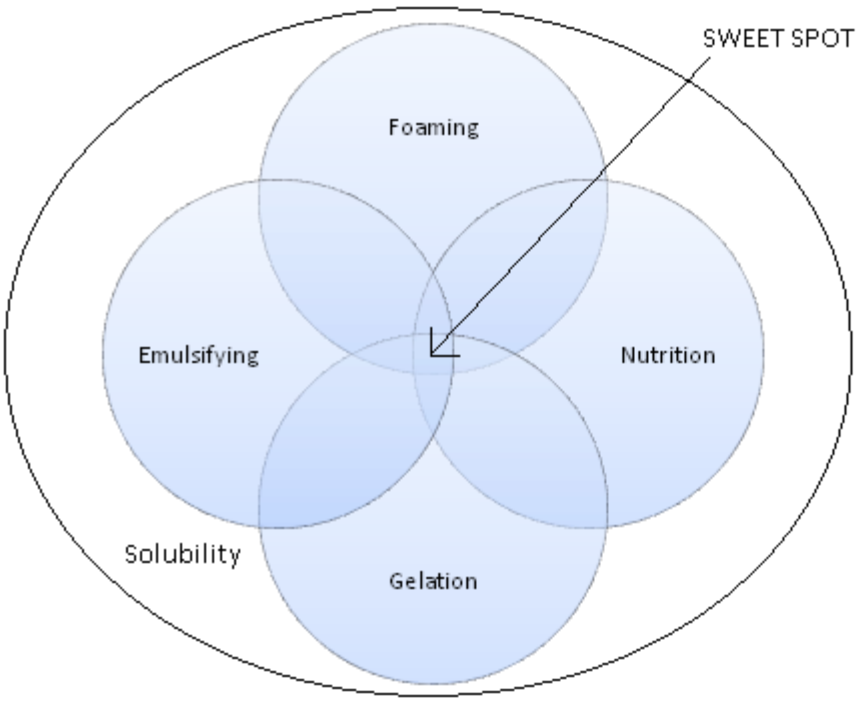


Figure 2: Finding the 'Sweet Spot' with physico-chemical properties

Compared to whole protein ingredients, the physico-chemical properties of a protein fraction are easier to analyse, and therefore their functionality is easier to predict during production. Functional reliability of a raw ingredient is of particular importance for large food businesses that manufacture products on a global scale. Consequently, protein fractions are more suited for formulation of ambient products (biscuits, crackers, snack foods) and functional foods such as sport nutrition products and TVPs (meat analogues). Meat analogues of 100% plant protein can mimic the texture, flavour and appearance of beef, chicken, pork and even fish. For example, making headlines recently this year in the United States (US), 'Beyond Meat' launched a 100% vegan burger derived from pea protein isolate that is reportedly identical in texture, taste and appearance to a beef burger (www.beyondmeat.com). Each burger provides 20g of plant protein, significantly less saturated fat, and is GMO, soy and gluten free. Bamboo cellulose and potato starch provide textural functionality and beet juice extract 'leaks' to mimic the red colour of meat juices. Plant proteins were originally added to processed meat products like burgers and sausages as a means of reducing formulation cost and improving yield performance. Introduction of plant-proteins to existing products or brands would undoubtedly improve diet quality and reduce reliance on animal proteins. Rather than employ the 'health by stealth' approach, a desire for honest and transparent product marketing has driven product placement of the 'Beyond Burger' next to traditional meat products in meat aisles, allowing consumers to make informed choices.

Whole protein ingredients (whole nuts, seeds, grains, legumes), as they contain a mix of macronutrients in addition to the protein, can have limited protein content and bioavailability, and potentially excessive energy content. To achieve a high protein content in a product of limited size, for example a snack, can be difficult if using whole protein ingredients. As Figure 3 illustrates, the relative amount of quinoa (3.5 cups) required to provide 30g of protein is excessive not only in size but also in energy (777 kcal) in comparison to just one small scoop of pea protein isolate. Consequently whole protein ingredients are better suited for formulation of chilled 'to-go' foods (salads, wraps and sandwiches), fresh and frozen 'ready-meals', and pre-made soups.

Figure 3: Serving size of selected food items required to provide 30g of protein.

The nature of whole protein ingredients will be more appealing to consumers seeking a less processed product, as with the 'Clean Eating' trend.

As the demand for plant proteins increases, research and development in ingredient functionality will expand and improve, and many companies and projects are already investing heavily in this area. By 2024, the European Institute of Innovation and Technology (EIT) in collaboration with 50 partners from 13 countries, will have invested over 1.6 billion Euros in a bid to develop sustainable food products, services and processes, with the aim of achieving a 40% reduction in greenhouse gas emissions across the European food system by 2030. The project, called EIT Food (www.eit.eu), includes the Israeli algae supplier 'Algatechnologies', the French plant protein supplier 'Roquette' and Dutch nutrition ingredient supplier DSM, along with numerous R&D companies and universities. The project aims to launch 350 new start ups in the 7 years of its life. In the United States, Hampton Creek is developing a plant protein database by analysing and cataloguing the physico-chemical functionality of thousands of plant proteins (www.eatjust.com). In September 2017, they received a patent for their protein analysis system called 'Blackbird' which breaks plant proteins down to their molecular level for functional analysis (properties including emulsification, protein quality and thermal stability). So far, this resulted in the launch of a novel mung bean protein isolate, and a vegan mayonnaise called 'Just Mayo' which harnesses the emulsifying properties of a yellow pea protein which is reportedly as good as the emulsifying abilities of egg. It is hoped that once such plant protein databases become widely available, product formulators will be better equipped to overcome the challenges in functionality, palatability and cost of current and novel plant protein ingredients.

6. Challenges in product development

5.1 Challenges in Functionality

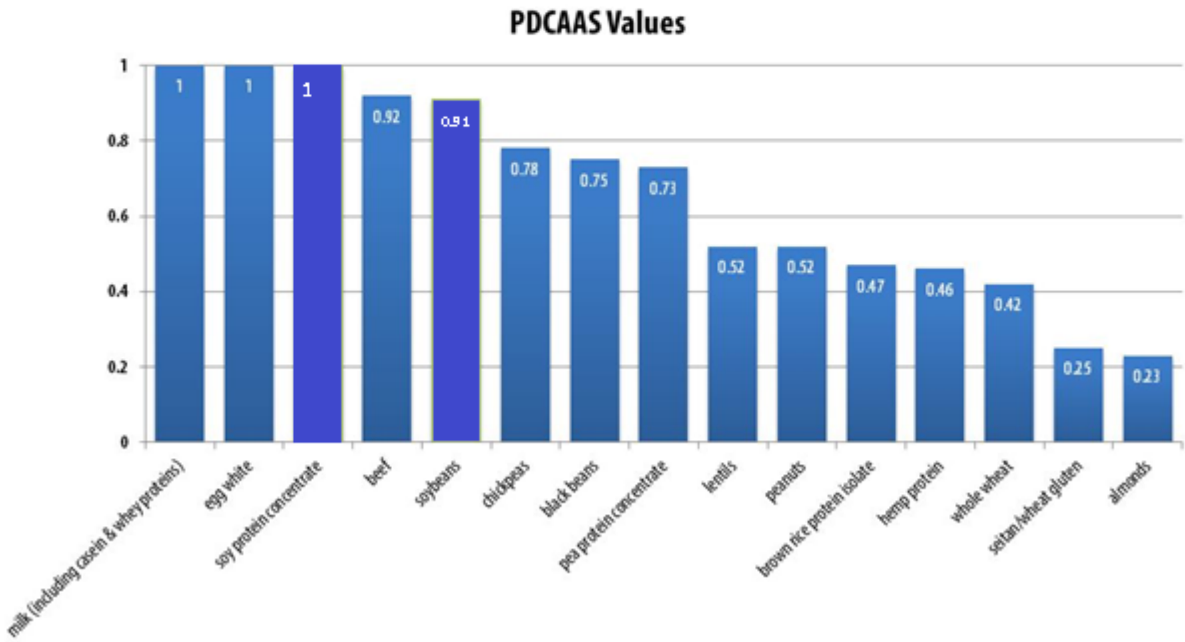
Nutritional Functionality

Nutritional functionality is concerned with protein *quantity* and protein *quality*. As previously discussed, ensuring a protein intake of 30g at each meal or eating occasion throughout the day would not only optimise muscle synthesis but also allow older adults to achieve the higher recommended daily protein intake of 1.0-1.2g/kg bodyweight (80-96g per day for a person weighing 80kg) [5,7]. Protein *quality* takes into account the amino acid content and ease of digestion and absorption of a protein ingredient. The most important aspect of nutritional functionality is the biological value or *bioavailability* of the protein, which refers to the proportion of ingested dietary amino acid that is absorbed in a chemical form suitable for it to be utilised for protein synthesis or metabolism [22].

The greatest inhibitors of protein quality are anti-nutritional factors which occur naturally in many plant proteins and/or develop during processing. These include trypsin inhibitors, tannins, phytic acid and uricogenic nucleobases; and those developed during processing include malliard reaction products (MRPs), protein-bound D-amino acids and lysinoalanine (LAL)[23]. Anti-nutritional factors significantly reduce the digestibility of plant proteins, and their occurrence and negative effects in plant proteins are generally higher relative to animal proteins.

The most widely used technique for assessing and comparing protein quality is the PDCAAS method (Protein Digestibility Corrected Amino Acid Score) which was adopted by FAO/WHO in 1991. Amino acid content is compared against a reference pattern (complete pattern=1) and the most limiting amino acid is then corrected for digestibility to provide a final score between 0 and 1. Figure 3 shows the PDCAAS values for some plant and animal proteins.

Figure 4: PDCAAS (Protein Digestibility Corrected Amino Acid Score) Values for common proteins; from www.soyfoods.org[24]



Although widely accepted, the PDCAAs method is limited in that it overestimates protein quality of products containing anti-nutritional factors, and overestimates the quality of proteins co-limiting in more than one amino acid [22]. There is evidence to suggest that the digestibility-reducing effects of anti-nutritional factors may be more marked in the elderly [25], therefore it is essential that protein quality assessment techniques are designed with these considerations in mind. The PDCAAS method, as it truncates scoring at 1, does not credit extra nutritional value to high quality proteins so does not accurately reflect the true quality of a protein ingredient [26]. Due to these limitations, it was recommended by FAO in 2011 that the DIAAS (Digestible Indispensible Amino Acid Score) method should replace PDCAAS, however it has yet to be adopted by any jurisdiction. DIAAS assesses true ileal digestibility of individual amino acids rather than a single faecal crude protein digestibility, and reportedly provides a more accurate assessment of protein quality for plant proteins than PDCAAS [27]. The practical value of the DIAAS as it relates to public health nutrition and its potential for development of nutrition information for labelling purposes is still under review. The FAO recommends that DIAAS cut-off values should be introduced for protein claims on nutrition labels, for example, 100 or more for a “high protein” food, and 75-99 for a “source of protein” [22]. Although protein quality cut-offs are in use in the United States and Canada [28,29], they are derived from the PDCAAS method and the protein efficiency ratio (PER) method respectively. The EU is yet to utilise protein quality measurements for labelling purposes.

In the UK, the reference daily intake (RDI) for protein i.e. recommended daily amount, is set at 50g (irrespective of body weight or physical activity) however it is not mandatory to state the protein content on traffic light labels. To qualify for an EU/UK protein content claim, the protein quantity must meet certain minimum criteria, however protein *quality* is not assessed. As illustrated in Figure 4, to be considered a "source of protein", at least 12% of the energy value of the food must be provided by protein; for "high protein", it is 20%[30]. As previously discussed, research suggests that 25-30g of protein per eating occasion is required to illicit muscle protein synthesis therefore the actual value of these protein claims as they relate to protein intake is limited. For example, a box of breakfast cereal that carries the nutrition claim "high protein" containing 22g protein per 100g and 21.1% of the energy value provided by protein (76 kcal out of 360kcal) only provides 7.6g protein per 40g serve, which if consumed in isolation for breakfast is insufficient to maintain muscle mass.

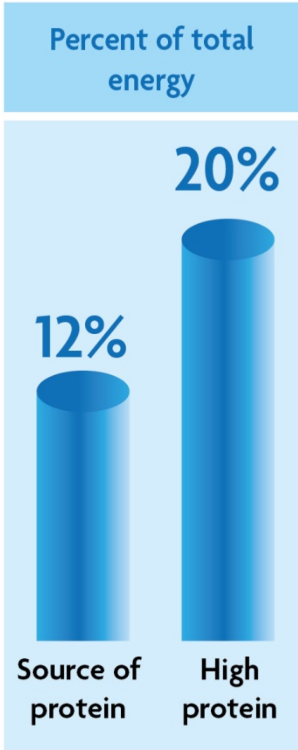


Figure 5: EU permitted protein nutrition claims

A major revision of the UK reference daily intake (RDI) for protein for older adults in conjunction with a standardised protein quality assessment measure would better equip product developers to help older adults optimise their protein intake. However until there is a large body of unequivocal evidence linking a reduction in population wide age-related muscle loss/ sarcopenia with increased protein intake, it is unlikely that the UK or EU will reassess protein nutrition claims.

Strategies can be employed at various stages throughout product development to improve nutritional quality by reducing or eliminating anti-nutritional factors and improving the amino acid profile of protein ingredients. These include; manipulation of the raw protein ingredient by selective breeding, fermentation and germination; and complementary blending of protein ingredients. Consideration should also be given to post-production storage and packaging.

Selective breeding

Processing techniques such as extrusion, roasting, thermal treatments, soaking at high temperature followed by cooking and dehydration, are frequently employed to eliminate anti-nutritional factors. However these processing techniques can be a source of additional costs for manufacturers. Selective breeding can be used to eliminate undesirable traits and enhance beneficial nutritional characteristics, thus reducing reliance on the aforementioned processing techniques. Genetic removal of lectins, reduction of phytate accumulation, and retention of α-amylase inhibitors in common beans can produce composite pulse flours that have improved nutritional profiles for the manufacture of biscuits and baked goods [31]. Selective breeding to produce cultivars of high nutritional quality may in part prevent or reduce the reliance on GMOs, which will be a great selling point for many environmentally-conscious consumers.

Fermentation and germination

Legumes are a viable option for protein fortification of baked goods, pastas and noodles, however as with many plant proteins they can be limited in their amino acid bioavailability and digestibility. Fermentation of legumes with lactic acid bacteria significantly increases the amount of total free amino acids (including EAAs), enhances in vitro protein digestibility, and significantly reduces the levels of anti-nutritional factors without negatively affecting technological and sensory characteristics of the intended product [32]. Fermentation of faba bean flour can increase the amount of amino acids from 7g per kg to as much as 16g per kg [33]. Fermentation can also significantly increase the content of antioxidants in legumes [34]. Germination can successfully improve in vitro protein digestibility of mung bean, pea and lentil seeds and decrease the levels of anti-nutritional factors [35].

Complementary blending

Apart from soy, quinoa and certain species of microalgae, plant proteins are limited in one or more EAAs, which reduces their protein quality score in comparison to animal proteins. A complete amino acid profile can be achieved by combining two or more inferior plant proteins that have complementary amino acids. For example, many legumes are limited by methionine and cysteine, but with the addition of brazil nuts (which contain a significant excess of methionine and cysteine) the overall amino acid profile of the product can be increased [36].

Protein complementation can assist in other areas of a design brief, for example certain plant protein pairings can minimise or maximise energy density, or improve the overall micronutrient profile of a product. Cereal grains in breads, limited in lysine, can be improved by the addition of high-lysine dulse protein (a red seaweed), which also brings blood-pressure lowering peptides to the formulation [37]. The online 'Vprotein' computational tool allows assessment of the amino acid profiles of differing food combinations however the list is not extensive and is limited to whole food ingredients only [36]. Availability of an online amino acid complementation database would greatly assist food manufacturers in developing complete plant protein products.

5.2 Challenges in Palatability

There are a number of desirable sensory attributes that define flavour quality and palatability. These include the immediate impact of the identifying flavour (i.e. strawberry, chocolate), rapid development of a balanced full-bodied flavour, compatible mouthfeel and texture, lack of off-flavours, and minimal/brief aftertaste. The word 'off-flavour' describes any unpleasant flavour including the perception of unpleasant taste, aroma, and other effects, such as astringency [38]. The texture (e.g., smoothness, coarseness, hardness, thickness, slipperiness, viscosity, etc.) can also have a large influence on flavour perception. Flavour, along with price, is the number one factor that determines consumer choice at point of sale, regardless of the consumers' stated ethical or health intentions [39]. Consequently, flavour is foremost in a design brief for any product developer. Protein fortification of an existing product or brand should avoid altering the original flavour as much as possible, as consumers will often remember and expect a specific taste or texture.

Creating desirable flavours and textures in high protein products is challenging. Unpleasant flavours can exist inherently in the protein ingredient itself; soy protein is known for its bitterness, pea protein for its beany or earthy flavour. Off flavours can also be generated by way of heat, processing, oxidation, pH fluctuations and interactions with other ingredients in the food matrix. Protein is particularly notorious for binding to other flavour ingredients. For example, the amino acids cysteine and methionine can form disulfide bonds with sulphur-containing flavours like mercaptans and thiols, which yields unpleasant burnt-rubber and cabbage off-notes. Many protein ingredients bring a grainy or chalky texture to a formulation, which occurs due to the high water-binding activity of proteins. The low solubility of proteins is a recognised challenge when developing beverages.

Numerous developments in ingredient research and process design have successfully reduced or masked many of the off-flavours associated with protein ingredients. Ingredient congruency can be employed to match ingredients that have similar flavour characteristics, for example the earthy flavour of pea protein would match acceptably with nuts and seeds in a cereal snack bar where an earthy flavour might be expected.

It is important to note that out-with the realm of protein fractions, food manufacturers primarily utilising whole foods high in proteins to create their products may not encounter the same challenges in palatability. Palatability is not as intrinsically tied to functionality and the physico-chemical properties of the ingredient, and a more natural approach to product formulation termed 'ingredient assembly' is employed. Consequently, techniques to improve palatability involve working with the raw ingredient in novel ways rather than modifying the physico-chemical properties of the raw ingredient itself.

5.3 Challenges in cost

With any new product design there are costs involved at every stage of development. A multitude of factors impact the feasibility of a product, and these can be grouped according to the initial marketing, technical, and financial considerations, as detailed in Table 3.

Table 3: Considerations for product development

MARKETING CONSIDERATIONS:	***determines initial product characteristics***
Consumer acceptability Market trends Product image (and resulting impact on company and existing market) Competitive positioning Intended market channel Price setting Promotion method (social media, tv, print, sampling) Promotion message (high protein, natural, organic, tasty) Legal requirements (labelling regulations) Nutritional requirements (protein content/quality, macronutrients, macronutrients, allergens) Ethical and environmental requirements (sustainability of raw ingredients) Distributor requirements	
TECHNICAL CONSIDERATIONS:	***determines feasibility of product design***
Ease of processing Raw material availability and attainability Functionality of raw ingredient (including nutritional function) Palatability of raw ingredient Reliability of ingredient quality Shelf life Equipment needs Human knowledge and skills	
FINANCIAL CONSIDERATIONS:	***determines feasibility of product development***
Costs of manufacturing Costs of distribution Costs of further development The investment required	

A final feasibility report will discuss any marketing, technical and financial constraints, assess anticipation of market success and the associated impact on the company and the existing market of various levels of product success. If identified constraints cannot be overcome then production will not go ahead.

Raw ingredient costs

Although plant proteins are significantly less expensive than animal proteins, protein fractions (concentrates, isolates, flours) are expensive, particularly if the ingredient is novel, and this can be the case for the newly developed plant protein ingredients on the market. Purchasing protein fractions at high-volume can reduce cost however this is often not feasible for smaller food manufacturers with limited budgets. In the UK, the majority (96%) of the 6,815 active food businesses are small and medium sized enterprises and their product output is largely pre-prepared meals and dishes, bakery, and sugar/chocolate confectionary, supplied to UK markets [40]. The more specialised the raw ingredient, the higher the risk the supply chain will face; ingredient growers need to be reassured of ongoing demand for the ingredient to justify the risk of supplying that crop in huge quantities. Although the UK food industry currently produces 52% of the food consumed in the UK, there is major reliance on raw ingredients sourced from abroad (46%), primarily from the EU [40]. Consequently, the food and beverage sector was included in a list of the top 10 UK sectors that most depend on the EU for intermediate inputs (raw ingredients) [41]. This is due to unfavourable UK growing conditions to guarantee supply and taste, zero manufacturing or limited supply in the UK (e.g. emulsifiers, dairy powders, enzymes, flavourings), lower cost available abroad due to global trading commodities or processing close to crop location (e.g. edible oils, sugar, packaging), UK demand outstripping supply, and centres for excellence for specific ingredients outside the UK (e.g. coffee whiteners in Northern Europe) [40]. Thus availability of raw ingredients has a significant impact on final product cost, particularly for UK-based businesses. It is unknown to what extent BREXIT will impact the supply chain for UK manufacturers. Uncertainty in this area does not foster economic growth however it is worth noting the historic strength of the UK food industry, which was the fourth fastest growing UK manufacturing sector by GVA between 1997 and 2015 with 27% growth [40] even taking into account the global financial crisis. Outside of tariffs, the Food and Drink Federation (FDF) reported labelling requirements to be the top reported non-tariff measure acting as a barrier to exporting [40] and this is likely to remain the case for companies wishing to continue trade post-BREXIT. The forecasted continuing increase in cost of imported raw ingredients (in part driven by the devaluation of the pound) could drive development and opportunity for local production of raw ingredients however this may be limited to specialist processed ingredients only. The low availability of arable land and the cool British climate will not allow for extensive crop production unless innovative, efficient, and sustainable production methods are developed.

7. Industry-identified challenges and opportunities

Consultation with the Protein For Life industry partners yielded a thorough analysis of the challenges faced and the opportunities derived by industry. These are described in detail with excerpts from conversations where appropriate. A semi-structured '*Interview Guide*' was developed to aid discussion, a copy of which is provided in Appendix 1.

- **Protein Content**

Although the industry partners had not yet been briefed in detail on the recommended protein requirements per serving size, concern was voiced regarding the potential difficulty of achieving 25-30g of protein per serving size without relying on protein fractions or animal proteins. For smaller UK-based companies this may be a considerable challenge considering the product segments they manufacture, namely chilled 'to-go' foods, pre-prepared ready-meals, and bakery. Although bakery goods have the potential for protein fortification with fractions, fresh meals with short shelf-lives are less suitable.

"I think it would be a challenge…when you are talking about mostly vegetable protein, it's nowhere near like having a lump of chicken or a steak. If it was a snack you would need 2 or 3 a day. But if it was a single meal occasion it might be a challenge."

"*I just want to re-iterate the fact again, that we are a chilled food manufacturer and there are lots of us in the UK making short shelf life products…with real ingredients. Big ambient food businesses…it's very, very different, the way they design and develop products."*

Achieving a high protein content using fresh ingredients was also viewed as a potential issue specifically for the older adult, as they might struggle with large portions sizes owing to an age-related reduction in appetite.

- **Protein Quality**

Although industry members were aware of what constitutes a complete protein and of the use of protein blending, and the variations in digestibility and bioavailability that can occur in different food matrices, protein quality was not valued as highly as protein content. This is mainly due to the lack of consumer awareness about protein quality, and the lack of an appropriate health claim/label to be able to support and develop an increase in consumer awareness.

"I think because there's not the knowledge with the consumer, I don't think the companies feel they need to do it. Because all the consumers see is protein, 'oh that's good for me', there's no kind of understanding that different proteins have different nutritional value."

"Not many people are picking up currently on the nutritional value if that makes sense, of the type of protein that you are putting in. We are starting to see very small amounts of interest in terms of the amino acid profile but it is a very, very, small amount at the moment."

It was generally acknowledged that as consumers and manufacturers increase their demand for complete protein solutions, ingredient suppliers will provide them. All members agreed that access to a protein ingredient database would be of huge benefit to the industry.

- **Palatability**

Many industry members discussed the potential issues with flavour and texture that can occur when using high concentrations of protein fractions. However most felt that ingredient developers were already successfully overcoming many of these issues by sourcing highly purified fractions with bland starting flavours, or suitably masking flavours to counteract off notes. The additional costs and the complexity attributable to masking would often preclude the use of that protein ingredient.

"The proteins that we saw 5, 10 years ago when it wasn't so popular, they were quite strong and very potent in terms of flavour but you see more and more proteins that are milder and bland in flavour because that's what we need when you are putting more and more in."

"Some of our [ingredient] suppliers are very large, very professional, they take 2 or 3 years to develop a product and they always launch it with very, very good support material. And that's obviously helpful for us. They do loads and loads of viscosity tests, they do brittle tests, they know a lot about their products. But you also have these smaller companies that do 1 or 2 proteins and obviously they don't have the resources so it varies incredibly."

"Off notes and bitterness are the issue with concentrations of certain ingredients. The first thing is avoidance, because if you have to do some masking you are going to be in trouble. This is why most of the bars – the high protein bars - in the market have very strong flavour. You have a lot with peanut butter, a lot with blackberries or blueberries or things like that, chocolate, to help with that one."

"There is a toolbox which is available in most flavour houses, if you have bitterness or other off flavours in a way coming from protein that you can mask, but then you have more costs."

For companies not working with protein fractions, palatability was not viewed as a major issue when developing whole plant-based products. However those companies are not currently creating products that contain plant protein equivalent to 30g/protein per serve, therefore it is possible that issues with palatability may emerge during product development.

- **Reliable supply chain**

Concern was raised regarding the long-term reliability of the ingredient supply chain, particularly for emerging protein sources. Many companies, due to the massive quantities of raw ingredients they require, are unable to commit to a supplier unless long-term supply can be assured. It may therefore take time for emerging protein suppliers to increase capacity, which will initially restrict many novel protein sources to smaller niche markets. It is also essential that production of these proteins is scalable to the quantities required, and environmentally sustainable. The majority of food companies have sustainability commitments ingrained in their company ethos, therefore it is essential for a company's image to support sustainable production methods.

"I think it's the scale thing, there's a lot of good suppliers out there and all the good suppliers that I've met are growing at the rate of noughts, it's unbelievable the growth that they are seeing. But it's about the scale to service the market."

"But it's a gradual process and it's going to take a long time. Even thinking about seaweed and seaweed harvesting, people are doing it, but to sustainably set up seaweed farms that's going to take years if not decades to do that properly. What about insect farms, and what about Mankai this random seed that's growing out in Israel...so it's all going to take time and learning."

"But then the story doesn't end there because the population globally is growing and in the future it could well be competition for different sources of ingredients with regards to the final use. So what do you do, do you plant a field with wheat to use that as flour that people can eat or do you plant that field with wheat and then take the wheat protein out and put it in a snack?"

"Because usually they are new companies with very cool stuff coming into the market but you have to be careful. If you are a small start-up and you are making a product and its going to be discontinued then it doesn't matter but for us, a large company that has brands, you have to be careful with the protection and the integrity of your brand."

A good example of suppliers meeting demand is the French company Roquette which is building a pea protein manufacturing plant at the cost of more than 300 million dollars to provide a processing capacity of more than 120,000 tonnes per year. This is in addition to its existing plant that has a processing capacity of nearly 100,000 tonnes per year. Construction began this year and production is expected to start in 2019.

- **Consumer awareness**

A consistent health message is required to inform older consumers why they need extra protein, how much they need, when they should eat it and in what form. Without this knowledge infrastructure, consumers will not perceive a need for protein, thus there will not be a demand for high protein products. These concerns were voiced by all industry members.

"In the UK we've looked at making products with 'source of protein' claims and...I'm talking about the overall consumer pool here, first of all, we still haven't managed to convince ourselves that the consumer is asking for more protein or is in need of more protein. I think to be honest if the market talked and everybody put protein on their packs we would do it as well. ***But we're not convinced that the consumer understands yet why and what kind of protein they would need****."*

Therefore it is essential to deliver a clear and concise health message to consumers that can in turn be harnessed by the food industry to aid development of specific products.

"If we invest in putting more advanced sources of proteins into our products then we have to find a way of getting that message to very average normal consumers....an alignment between the nutritionists both in the universities on this project and the nutritionists in industry, to try to drive to the consumer a trustworthy communication around why you need protein."

- **Consumer acceptance and marketing approach**

In thinking ahead to product development of high-protein sustainable products for healthy ageing, there were conflicting opinions about the potential consumer acceptance. Some perceived that older adults would not be as accepting of new ingredients, flavours and textures as their younger counterparts, nor be as likely to alter their eating behaviours at a later stage of life. There was the concern that because older adults are not typical purchasers of high-protein functional products they would not naturally seek out such a product even if developed specifically with the older adult in mind.

"And I mean plant-based is more of a millennial generation type demand, these are just assumptions that the older consumer may have more of a traditional diet so may not be so accepting of alternatives."

"But I think that's a challenge to a broader age group to be fair as well but I think particularly with the older market, they know what they like and I think it will be hard to change that routine."

"I think it's always better if you can build awareness because if it's a very functional product they tend to be more expensive and more exclusive products and it will be a consumer that is more affluent and more well informed. If you want to really reach the bigger parts of the population it needs to be something more simple. I think the highly functional products give the impression that they won't taste as good as other products."

The alternative viewpoint regarded older adults as more open and engaged in current food and health trends.

"What I mean is the older population they are becoming very savvy and want to have not just a long life but a healthy life, to be able to travel and do what they want to do. So I think there is a portion of the population that is aware what is happening, they are reading, watching TV, radio and there's a lot of information about that."

"It's quite interesting because we've done a big piece around the ageing population and it's not quite as traditional as I always would have thought. I think they've travelled more and eaten a lot more foods compared to what my grandparents would have."

With this in mind, there was a general discussion about the marketing approach that would best serve the target consumer group, with an awareness of avoiding patronising or ageist messages.

"But in terms of older people my question would be do they realise they need more protein? And it's very difficult to market it without being patronising."

"Definitely in the sense that you wouldn't want to make them feel like they are ageing. Protein is required for healthy ageing, but some consumers would say 'well I don't need that, are you trying to say I'm old?' The marketing around it would need to be quite sensitive and that is really about living longer, better healthy rather than you're getting old and you need it."

- **Labelling regulations**

There was overall agreement that the current UK protein labelling requirements for 'source of protein', and 'high protein', were adequate for the current market. It was felt that any changes to current nutrition labels would have to avoid altering the standard nutrition panel/ traffic light labels, as the intention was not to encourage excess protein (and possibly energy) consumption in younger age groups. Changes to nutrition labels, for example the addition of information regarding protein quality, could also be confusing for consumers. A protein nutrition claim specifically aimed at older adults for healthy ageing could aid product marketing however there was scepticism regarding the likelihood of such a claim obtaining EU approval. Existing health claims that have been utilised for marketing products to older adults include Vitamin D and Calcium, which have the approved EU health claims "contributes to/needed for...the maintenance of normal bones"[42]. It is important to remember that the success of age-related health claims rely upon the consumer having pre-existing knowledge of age-associated health issues.

"But I think it depends what the consumer knows and understands, you know calories, protein, fats, there's guidelines around what your daily intake should be and consumers have started to understand that, but if you start to change it or start to label things differently then that's going to be quite confusing for the consumer. So it's about how you would go about informing that change."

"With Brexit it makes it harder. There's lots of claims out there that there's a lot of scientific data for, but until it's approved by EFSA [European Food Safety Authority] there is just no way you can make those claims. So I think it's got to be a change at EFSA before there's any value for manufacturers making any changes in the approach that they use."

"And claims for example, regulations about the claims, now speaking about sarcopenia, can you claim that your product is going to reduce sarcopenia and if so what does it have to have? Which proteins and what are the levels and which vitamins?"

"I think it's interesting, the digestibility, but do consumers really understand that and does it mean anything to them? And on front of pack you are limited to how much you can tell them and then you're talking about above the line with a massive spend like a TV advertisement which would be about education. So we're probably not there yet in the UK with the amount of knowledge that consumers have, and yet you still have a challenge with how much information because a little bit of information can be a good thing, but I think it's at the right level at the moment. It's already a struggle for consumers to comprehend all the nutrition information."

- **Cost**

Cost was frequently mentioned by all industry members as a major limiting factor in product development. In particular, the price of the raw ingredients (mainly protein fractions), and whether any resulting increases in final product cost would be accepted by the consumer, were major concerns.

To develop a product that is going to be purchased and consumed on a regular basis – as is the intention to achieve optimum protein intake, the price setting has to be affordable for the consumer in comparison to existing products.

"Our investment in the process sometimes has to be quite minimal and we have to make things to cost. You know if you want to make a one pound sandwich then imagine your raw ingredient costs have to be quite low. So that is a challenge for us, how can we be flexible, cost effective and yet still meet the consumer needs?"

"Yes, cost, because the perception is that if it's not got meat in it then it's going to be cheaper but that isn't the case."

"Consumers aren't willing to pay a lot more. Price, certainly in food-to-go and a lot in the chilled food aisles, price is probably the number one determining factor."

"If you put products with more protein and a higher cost in the market you are asking for affordability. But you have a difficulty in getting the balance right between affordability for us, and the consumer."

"Cost is a huge barrier on all product development. It can be quite challenging to develop the product, to meet the criteria, because you have your taste, your texture, your cost, your dissolvability, your legal...there's lots of elements. If cost wasn't an issue I think we probably could do it."

8. Potential market opportunities

Considering the nutritional constraints of the design brief - namely spacing protein intake throughout the day and ensuring 25-30g of protein per meal or eating occasion - it is appropriate to consider product designs as they relate to eating occasions. What follows is a discussion of design concepts for breakfast, lunch, dinner, and snacks.

BREAKFAST

Breakfast has been identified as a protein-deficient meal for many older adults therefore is a key eating occasion to target. The traditional 'tea and toast' breakfast is not conducive to maintaining muscle health, and highly processed meat-based breakfast items such as bacon and sausages are high in saturated fat and potentially carcinogenic if eaten on a regular basis.

Traditional British breakfast options include:

- Cereals
- Dairy-based beverage/ Yoghurt
- Bakery

A review of the current high-protein market offerings for these three product categories will give an overview of the state of the art in this area, and may help to identify potential opportunities for the Protein For Life design brief.

Cereal-based:

A breakfast cereal could be a viable vehicle for boosting protein intake. A review of high-protein products currently available identifies porridges, and granolas.

Porridge is a suitable breakfast option for older adults experiencing chewing and swallowing difficulties, is a traditional breakfast food for older generations, and has a recognised health halo. High protein porridges currently on the market are listed in Table 4, in descending order of protein content. Notably, the two products that contain plant-proteins only (soya, rice, linseed) have the lowest protein content (10-10.5g) and also the lowest calorie counts (144-201cals). The average protein content per serving size of standard porridge is 5g. It may be possible to boost the protein content by adding additional plant-based protein fractions, particularly if flavourings were added to help mask any off-notes. The '*Complete Protein Porridge'* with the highest protein content per serve (22g) is available in a range of flavours probably for this reason.

Table 4: High protein breakfast cereals

PRODUCT	PROTEIN PER SERVE	PROTEIN SOURCE	CALORIES PER SERVE	SERVING SIZE
Complete Protein Porridge	22g	Soya protein concentrate, Soya lecithin, Milk protein concentrate	282	75g
Oomf Protein Oats	22g	Whey protein	281	75g
Mornflake GO! High Protein Porridge	14g	Skimmed milk, Soya protein isolate	222	36g
Fuel 10k Porridge Oats	14g	Milk protein concentrate	265	70g
Whites ActivOat	**10.5g**	Soya protein	**144**	40g
ProFusion Proats	**10g**	Rice protein, Milled linseed	**201**	50g

Compared to high-protein porridges, there are not as many high-protein granolas on the market (Table 5). The average protein content per serving for standard granola (non-protein) is 5g, the high-protein varieties have double or triple that amount. A potential challenge would be achieving the sweet flavour that is expected in granola, however sweeteners and/or dried fruit could be acceptable alternatives to added sugars. There is more scope with granola to add different grains, nuts and seeds, and a greater range of flavours and textures to mask higher protein fraction contents. Quinoa, being a complete protein, may be a suitable option. Complementary blending of two or more plant protein fractions will also provide all the essential amino acids.

It is worth mentioning that the design concept for granola can potentially be applied to the development of high-protein breakfast cereal bars. Cereal bars have the potential to cross-over into the snacking category and could boost the per-eating occasion protein intake if eaten with a meal.

Table 5: High protein breakfast granolas

PRODUCT	PROTEIN PER SERVE	PROTEIN SOURCE	CALORIES PER SERVE	SERVING SIZE
MyProtein Protein Granola	15g	Soy protein, milk protein, soy lecithin	170	30g
Lizi's High Protein Granola	10.8g	Soya protein flakes, Soya protein crispies (which contain isolated soya protein and rice flour)	180	40g
Nestle Shreddies Max Granola	10g	Soya crisp (soya protein isolate), Soya protein isolate, Soya lecithin	242	45g
The Protein Works Protein Granola	8.35g	Isolated soya protein, whey protein iolate	201	50g

Beverages and yoghurts:

Products currently on the market are listed in Table 6. These products offer greater convenience and could cross-over into the snack category if eaten later in the day. They all have added vitamins and minerals, most commonly Vitamin D and Calcium, therefore there is the potential to link a health claim with bone health – an established age-related health concern. The consistency and texture of these products may be more suited to older adults with chewing and swallowing difficulties. Again, it is interesting to note in these products that protein content decreases as the content of animal-protein decreases. The 'Nestle Breakfast Essentials' is only available in the US, however it has been included to provide an example of the type of product that can arise with a cross-over into the functional product category.

Table 6: High protein breakfast beverages and yoghurts

PRODUCT	PROTEIN PER SERVE	PROTEIN SOURCE	CALORIES PER SERVE	SERVING SIZE
Weetabix On the Go Breakfast Drink	21g	Milk protein	208	275ml (Has added calcium, iron and B12)
Nestle Breakfast Essentials*	15g	Milk protein concentrate, soy protein isolate	220	236ml (Has added vitamin D, calcium, and prebiotic fibre)
Alpro Go On yoghurt	**9.3g**	**Hulled soya beans**	**107**	150g (Has added vitamin D and calcium)

Bakery:

High protein breads are available in most UK supermarkets (Table 7). These products are only useful if eaten in combination with other protein-containing items. For example, one piece of 'LivLife' toast (6.7g) with one poached egg (6g) and an 'Alpro Go On' yoghurt (9.3g) would total 22g of protein. There may be the potential to increase the protein content in breads, however it is a challenge to maintain good texture. Added non-wheat proteins can interfere with the gluten structure of the dough, both due to their water-binding effects and their inability to create disulfide-bonds when kneaded (essential for structure) [43]. Non-wheat proteins can also impact the running of automated equipment. The addition of wheat protein isolate is often required to counteract the effects of added non-wheat proteins. Algae is reportedly a good alternative as it does not alter the dough structure, and raw pea flour can make up about 30% of the total flour of a bread before taste and texture become significantly affected [44]. Pulse flours, due to their effect on dough structure, may be more suited to flat breads, tortillas and pitta breads, rather than your typical breakfast loaf.

Table 7: High protein breads

PRODUCT	PROTEIN PER SERVE	PROTEIN SOURCE	CALORIES PER SERVE	SERVING SIZE
Hi-Lo High Protein Bread	6.8g	Wheat protein, Soya flour, Soya protein	172	2 slices (66g)
Warburtons High Protein Loaf	8.0g	Navy bean flour, Chickpea Four, Pea	132	2 slices (58g)

		protein, Wheat protein, Soya flour		
Tesco Finest High Protein Loaf	10.2g	Wheat protein, Soya flour	178	2 slices (66g)
LivLife Low Carbs Seriously Seeded Loaf	13.4g	Wheat protein, kibbled soya, soya flour	136	2 slices (52g)
Dr Zacs High Protein Loaf	30.2g	Wheat protein isolate, pea protein isolate, soya flour, brown linseed	301.9	2 slices (126g)
Lidl High Protein Roll	30.7g	Linseeds, wheat protein, soya flour, soybean meal	298	1 roll (115g)

LUNCH AND DINNER

Typical lunch options include sandwiches, wraps, salads, and soups (chilled, canned and dehydrated). Dinner items include fresh and frozen ready-meals, prepared meal accompaniments, and meal staples (pasta, noodles, rice, meat replacements).

Due to the vast range and multi-ingredient nature of the above items, it is not feasible to review a representative or comparable selection of current market offerings.

Sandwiches, Wraps, Salads:

The average pre-made plant-based salads, wraps and sandwiches provide just 3-5g protein per serve on average. The only feasible way to increase the protein content in these products without relying on animal proteins would be to use high-protein breads and meat replacements. Two pieces of high protein bread could add 10-14g of protein. Salad dressings, sauces, and sandwich fillings may offer a liquid/semi-liquid vehicle for a protein fraction however the effects on palatability would need to be tested. The current consumer base for plant-based chilled ‘to-go’ foods is highly skewed towards vegans, vegetarians and flexitarians. It may be unrealistic to be able to significantly increase uptake of these products by consumers out-with the vegan/veg/flex consumer base, in a short period of time. Successful product launches rely on an existing target market.

Soups:

Soups are a realistic vehicle for the addition of protein fractions, and tend to be widely accepted by the older generation. They also have a health halo. The use of novel and exciting flavours can attract younger consumers. A small selection of high-protein soups are already on the market, as summarised in Table 8. The *‘Batchelors Cup a Soup’* only contains 4.3g protein per serve, but it may be possible to increase the concentration of protein fractions without compromising palatability.

Increasing the portion size would also help however this would increase the price and also potentially push the 'Cup a Soup' out of the 'snack' category. Soups are often eaten with another meal item (i.e. a sandwich) so there is the potential to boost protein with a complementary product.

Table 8: High protein soups

PRODUCT	PROTEIN PER SERVE	PROTEIN SOURCE	CALORIES PER SERVE	SERVING SIZE
Batchelors Cup a Soup High Protein (Mediterranean Veg & Bean)	4.3g	Potato starch, Wheat protein, Red kidney beans	84	96g
I Am Souper Supergreens Soup	9.8g	Green Peas, Pea Flour	184	390g

Prepared Fresh and Frozen Meals:

Meals intended to be eaten for dinner are typically larger and have more components therefore a combination of high-protein meat replacements, high protein grains and pulses, and protein fractions, could quite feasibly create a prepared meal with minimum 30g protein per serve. Plant-based products that replicate the taste, texture and aroma of meat could be a viable option for older consumers wishing to reduce their meat consumption without compromising on their flavour preferences.

SNACKS

The snack category offers a plethora of product types for protein fortification, however the design brief must consider more than just protein content. Protein claims on snack products may encourage consumers to buy products that are unsuitable in terms of energy density, sugar, and saturated fat content. Older adults may require extra calories due to illness or frailty, however age-related muscle loss begins at age 40, therefore it is essential that the design brief aligns with recognised dietary guidelines in terms of salt, sugar, saturated fat, and energy density for the younger adult.

Functional Foods

As the sports nutrition market was historically developed for function, consumers were willing to compromise on taste and often pay a premium in return. Now that the protein market has gone mainstream, there is greater demand for a great-tasting and affordable product, and tight competition in this category has pushed the barrier in terms of ingredient functionality. A wide range of plant-based protein fractions, natural and artificial sweeteners, and complex flavour blends, allow product developers to close the gap between function and flavour. Consumers often seek an element of permissibility or guilt-free snacking in their product choices, and this is an area that could be explored for the Protein For Life design brief.

Age-specific functional nutrition is currently dominated by dairy-based products such as yoghurts, beverages and spreads that either utilise Calcium, Vitamin D, or cholesterol health claims - an example being the cholesterol-lowering product 'Benecol'. There may be the assumption that functional products are more expensive, exclusive and poor in flavour, therefore without a clear and concise health message to overcome these negatives there is the risk that functional products would flop in the older consumer group. There is a potential for success if flavour can be optimised and the product made affordable.

9. Concluding remarks

The unsustainability of animal proteins is undeniable. The Protein For Life project presents an opportunity to develop a new set of sustainable design rules with the food industry, and the opportunity to test them on a specific population group that is experiencing a specific health issue.

There are technical challenges relating to the palatability and physico-chemical functionality of plant protein ingredients however it is evident that the industry is well equipped to overcome these challenges, owing to the extensive research and development capabilities, innovative forward thinking and excellent technical skill set.

The nutritional design constraints of the Protein For Life project present a challenge to the industry due to the limitations of plant proteins as ingredients. It is essential to achieve optimal protein quality, including a complete amino acid profile and a bioavailable matrix. There are pre-processing techniques (selective breeding, germination, fermentation) and formulation techniques (complementary blending) that can feasibly overcome these issues, however the cost implications may be prohibitive. The greatest nutritional constraint is achieving the optimum protein quantity of 25-30g protein per serving size or eating occasion. This is achievable using plant protein fractions however protein fractions are not suitable ingredients for all product categories. Unfractionated plant protein ingredients contain significantly less protein per gram therefore a greater volume of raw ingredient (often an unreasonable amount depending on the product) is required to reach the 25g threshold. This can be restrictive both financially and from a design perspective.

As with any new product development, maintaining low production costs is essential. Although the cost of novel protein ingredients and innovative production techniques may initially be prohibitive, ongoing consumer demand for sustainable and healthy products will drive down production costs.

The greatest challenge faced by the Protein For Life design brief is the associated target consumer base. Lack of consumer awareness about the health implications of protein intake for healthy ageing translates to a lack of consumer demand, and this is an issue for the longevity of high protein products aimed at the older adult. It is possible that only a small percentage of the older adult consumer base has a real understanding of the health reasons for requiring extra protein in the diet, and also of what the best sources, quantities and timings of protein intake should be. Developing a clear and concise message is critical, as is the format and delivery of the message, and questions remain about whether this should be guided by a nutrition label, health claim or public health campaign.

Recommendations for future research would include investigation into the nutritional properties and capabilities of plant protein fractions in relation to muscle maintenance and healthy ageing. Development of an accessible protein ingredient functionality database would be hugely beneficial to the industry. More research is needed to investigate current consumer knowledge, views, perceptions, and behaviours, in relation to protein sources. Collaboration between academia and food regulatory bodies, i.e. Public Health England, the Scientific Advisory Committee on Nutrition (SACN), the British Nutrition Foundation (BNF), EFSA, is required if a novel protein-related health claim is to be developed for delivering a health message to consumers.

10.Appendix 1: Interview Guide

CURRENT PROTEIN USES

Q1. What type of products do you currently work with?

(Refer to appendix 1 for list of product types)

Q2. Which of your products (if any) carry the following health claims:

'Source of protein' (minimum 12% of total energy)
'High in protein' (minimum 20% of total energy)

Q3. Which additional health claims, if any, do you include on these products, and why were these selected? *(See appendix 2 for approved health claims)*

Q4. What marketing terms, if any, do you include on these products, and why were these selected? *(Prompts: Fresh, clean, natural, traditional, authentic, pure, original, home-made, hand-made)*

Q5. Of the products that contain proteins, what are their primary/secondary protein sources?

Q6. What were the reasons for choosing these protein sources?
(Prompts: taste, operational costs, blendability, functionality, availability, nutritional quality, consumer acceptance...)

Q7. Of the products that contain plant-based proteins (if any), what challenges did you encounter when developing the product and how did you overcome these?
(Prompts: functionality, blendability, palatability...)

Q8. Is there a limit in terms of functionality/taste in how much plant protein you can include in a product and if so, how might this be overcome?

FUTURE PROTEIN USES

-Reformulations

Q9. Are you intending to reformulate (or have you already) any of your existing products or brands to increase the protein **content**, and if so, which ones and why?
(Prompts: to meet health claims, to satisfy consumer demand...)

Q10. Are you intending to reformulate (or have you already) any of your existing products or brands to alter the protein **source**, and if so, which ones and why?
(Prompts; to improve texture/flavour, lower costs, improve brand image..)

Q11. Which protein sources are you intending to use for these products, and why?

Q12. What type of consumer are you targeting?

-New products

Q13. Aside from the Protein For Life project, are you intending to develop new products that contain plant-based proteins, and if so, why?

Q14. What type of product are you intending to develop? *(Refer to Appendix 1)*

Q15. Which plant-based proteins are you intending to use and what factors were most important in making that selection?
(Prompts: flavour/taste, consumer acceptance, sustainability, availability, cost, nutritional quality, blendability, function...)

Q16. What type of consumer are you targeting?
(Include a discussion of the older adult as a consumer)

Q17. What do you consider to be the greatest challenges in developing a plant-based high-protein product?

Q18. Which factors have the greatest impact on final cost when developing a product?
(Prompts: technical, research and development, consumer testing, blending, protein analysis, ingredients..)

...and do you see any of these being particularly affected by the use of plant proteins?

-Knowledge

Q19. What do you consider to be the biggest challenges in developing a high-protein product for the older adult?
[Prompts: taste, consumer acceptability, profitability...)

Q20. Which additional micronutrients or macronutrients do you consider might be of importance when developing a high-protein product for the older adult?
(Prompts: vitamin D, calcium, sugar, low-GI, fat)

Q21. What do you consider to be the biggest challenges in marketing high-protein products to the older adult?

Q22. What do you consider to be the biggest challenges in marketing a plant-based protein product to the older adult?

Q23. What do you consider to be the greatest gaps in knowledge/skills in the food industry specific to the development of plant-based protein products?

Q24. What areas in product development do you think academia could assist with specifically?

Q25. What support services, if any, would you value/desire from a protein/ingredient supplier?

Q26. Are there any ways in which government or food regulatory bodies could assist with in product development for high-protein products for the older adult?

Appendix 1:

Product Category	Product type	Specific
Complete Meal (breakfast/lunch/dinner) Meal component/ingredient Snack	Beverage	Liquid (Dairy-based) Liquid (Non-dairy) Powdered form (Dairy-based) Powdered form (Non-dairy)
	Grain-based	Cereals Pasta Baked goods (breads, cakes, biscuits,)
	Dairy	Cheese Yoghurt Ice-cream
	Meat-based	Processed meat Prepared meals
	Functional products	Sports nutrition Health bars Nutritional supplements Meal replacements Free-from Vegan (Quorn, Tofu)
	Miscellaneous	Soups and sauces Dressings/Dips
	Confectionary	Chocolate, Sweets

Appendix 2:

Approved Nutrition Claims:

Energy-reduced, Energy-free, low fat, fat free, low saturated fat, saturated fat free, low sugars, sugars free, with no added sugars, low sodium/salt, very low sodium/salt, sodium-free or salt-free, no added sodium/salt, source of fibre, high fibre, source of [vitamin/mineral], High in [vitamin/mineral], contains [nutrient/substance], Increased [nutrient], reduced [nutrient], Naturally/natural, source of omega 3 fatty acids, high omega 3 fatty acids, high monounsaturated fat, high polyunsaturated fat, high unsaturated fat, light/lite, natural/naturally.

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