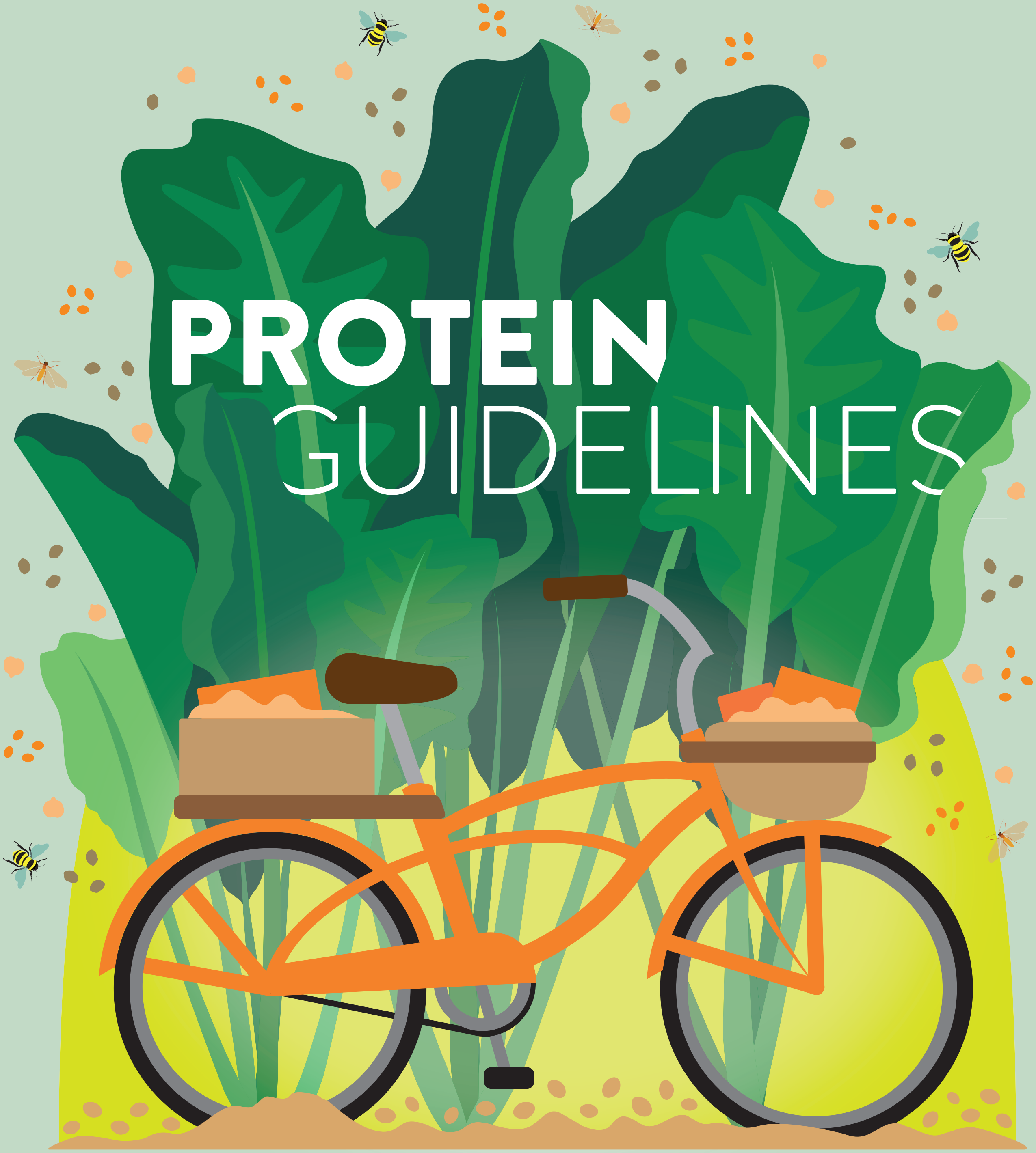
PROTEIN GUIDELINES



Why the Time is Right for an Update.

WHITE PAPER REPORT

Protein Guidelines
Why the Time is Right for an Update

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Executive summary

Interest around protein, sources and intakes, has been advancing rapidly. This has been fuelled by expanding global populations, environmental concerns and a growing research evidence-base. Unfortunately, in the United Kingdom and elsewhere many protein guidelines are fast becoming outdated. This is both in terms of *'sources'* of protein i.e. where we should obtain our dietary protein from and *'how much'* protein we need. This report examines where we are at present in terms of protein guidance and discusses where we need to go. Overall, the findings reveal that:

- **Food-based guidance is inconsistent -** Many organisations and societies are now compiling food-based dietary guidelines with a sustainability element – though there are variations in what this constitutes.
- **Protein guidance varies -** Most organisations mention the need for reductions in animal protein but the range of 'alternative' protein sources varies markedly as does the definition of 'plant-based'.
- **Advised protein intakes are based on dated methods -** Regarding 'protein intakes' most organisations have based these on studies using nitrogen-balance methods. These are now outdated with new isotope and amino acid oxidation methods suggesting that protein intakes guidelines should be *higher* in some populations.
- **Protein requirements may be higher than anticipated -** Some scientists have calculated that minimum protein requirements could have been underestimated by as much as 30-50% which translates in practice to 1.5-2.2g/kg-day of a variety of high-quality protein.[1] This is substantially higher than current recommendations of 0.66-0.8g/kg-day. Younger and older adults, in particular, may have increased protein requirements.
- **Protein quality has been redefined -** Previous methods focus solely on a food's amino acid profile. It has been proposed that updated definitions of protein quality should also encompass quality of health and environmental outcomes related to specific food sources of protein.[2]
- **Evidence on the value of 'protein distribution' is emerging -** A growing body of research suggests that further emphasis should be given to protein distribution i.e. promoting an even and balanced pattern of protein intake across the day as new evidence links this to optimal muscle protein synthesis.
- **The definition of 'plant-based' needs to be formally and consistently defined -** This definition varies between organisations and studies alike. Uniformity is needed to move this field forward so that science is not misrepresented.
- **Protein needs are multi-faceted -** Finally, when compiling protein guidance this should encompass several core central elements including: sources, intakes and timings.

It seems that the time could now be right for organisations to re-evaluate protein guidelines. Consumer trends are changing and the evidence-base has shifted. Bearing this in mind, we hope that you find this report useful when considering updating protein guidelines.

Introduction: Where are we at?

Population growth coupled with limited natural resources means that there will be deficits of high biological protein in coming years.[3]

Here are a few figures worthy of consideration: At the beginning of the century the world housed around 1.6 billion inhabitants, which expanded to 6.1 billion by the end of the 20th century.[4] It has been further projected that **the population will surge to 11.2 billion by the time we reach the 21st century (2100 years).**[5]

These unprecedented levels of population growth now appear to be shaping governmental, economic, environmental, health and food policies.[6] In the case of protein, the movement away from animal sources is beginning and the utilisation of alternative proteins, including plant proteins is starting to enfold.[7]

Most recently, the EAT-*Lancet*[8] report has collated evidence and viewpoints from more than 30 world-leading scientists from 16 countries globally about how to keep the global food system within environmental limits. This document is the cornerstone of things to come with Professor Walter Willett and fellow authors reporting that: ***"Healthy diets have an appropriate caloric intake and consist of a diversity of plant-based foods, low amounts of animal source foods,*** *unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars".*

Equally, whilst evidence about the need to consume 'sustainable' protein sources has been mounting so has the evidence about the need to update protein 'intake' recommendations.[1, 9, 10] For example, in the United States the International Protein Board[a] concluded that **"there is a need for 'global harmonisation' of protein recommendations as current guidelines and dietary benchmarks are largely based on outdated science and erroneous methodologies".**

Similarly, in the United Kingdom the Department of Health[11] **protein intake recommendations were established in 1991, which is now approaching three decades ago.** These protein requirements were based on observations of free living populations, relying on the accuracy of reported intakes. They were also derived from nitrogen-balance studies conducted mostly in the 1970s.

Getting the right 'protein balance' is important. In changing times 'protein balance' is now beginning to encompass a whole new meaning – where the protein is sourced from, its quality, the amounts needed, its implications for health and its wider environmental impact. This report covers some of these important issues.

[a] https://www.nutraingredients-usa.com/Article/2019/03/26/There-is-a-need-for-global-harmonization-of-protein-recommendations-IPB-chief Dr Wildman.

SECTION 1

How much protein do we really need?

Past Methods

The ‘nitrogen balance’ technique has long been regarded as the “gold standard” method for determining protein requirements.[1] This nitrogen balance approach has been defined as: *“The difference between nitrogen intake through food and the amount of nitrogen lost in body waste - in healthy adults the protein requirement is the amount needed to achieve zero nitrogen balance (maintenance)”.* [b] As seen in Section 2, most published protein requirements are based on this method.

Using ‘nitrogen balance’ methods most protein recommendations are set at 0.66 and 0.8g/kg-day as the Estimated Average Requirement (EAR) and Recommended Dietary Allowance (RDA), respectively.[12] One meta-analysis[13] collated and evaluated protein requirements using data from 28 nitrogen balance studies. Authors concluded that for healthy adults the EAR and Reference Nutrient Intake (RNI) for high-quality protein was 0.66g/kg-day and 0.83g/kg-day, respectively.

The EAR is the protein intake level at which the needs of 50% of the population will be met. The RDA now referred to in the UK as the Reference Nutrient Intake (RNI) is the amount of a nutrient that meets the needs of 98% of the population. These are useful benchmarks rather than ‘optimal intakes’ derived for specific health outcomes.

Evolving Science

Over the last few decades' new novel methods of determining protein requirements have been founded. As muscle is in a constant state of turnover stable isotopes have been identified as an effective method for the study of protein metabolism, as multiple amino acid tracers can be used simultaneously.[14] The ‘Indicator Amino Acid Oxidation’ (IAAO) method has also been validated and compared against nitrogen balance methods.

The IAAO method has now been used in human studies for more than a decade and is based on the principal that: *“When one indispensable amino acid (IDAA) is deficient for protein synthesis, then all other IDAA, including the indicator amino acid, will be oxidized. With increasing intakes of the limiting amino acid, IAAO will decrease, reflecting increasing incorporation into protein. Once the requirement for the limiting amino acid is met, there will be no further change in the indicator oxidation”.*[15]

This method is considered to be a robust and reliable way to determine total protein requirements and has been used and validated in different species, across the life cycle and in disease populations.[15] Since the IAAO method has been tested it has come to light that protein requirements using nitrogen balance approaches may have been underestimated.

[b] https://www.efsa.europa.eu/en/press/news/120209

For example, **some scientists have calculated that minimum protein requirements could have been underestimated by as much as 30-50% which translates in practice to 1.5-2.2g/kg-day of a variety of high-quality protein**[1] (Table 1). This is substantially higher than current recommendations of 0.66-0.8g/kg-day.

Table 1: Protein requirements based on IAAO methods

Author	Study population	Protein requirements
Pencharz *et al.* (2016)[1] Canada	Adults	1.5-2.2g/kg/day of a variety of high-quality proteins.
Courtney-Martin *et al.* (2016)[12] Canada	Young adults and elderly men/women	0.9 & 1.2g/kg/day as the EAR and RDA, respectively.
Elango & Ball (2016) Canada	Pregnancy	1.2 & 1.52g/kg/day during early (~16 wk) and late (~36 wk) stages of pregnancy, respectively.
Rafii *et al.* (2015)[16] Canada	Older females	0.96 & 1.29g/kg/day as the EAR & RDA respectively
Elango *et al.* (2010)[17] Canada	Adult men	Mean requirements determined to be 0.93g/kg/day

Key: EAR, Estimated Average Requirement; IAAO, Indicator Amino Acid Oxidation method; NR, not reported; RDA, Recommended Dietary Allowance.

Growing evidence from stable isotope, IAAO methods and human intervention studies indicate that:

- Current protein recommendations are too low and inadequately support optimal stimulation of muscle protein synthesis in *all* populations.[18]
- Protein requirement estimates could be 40% higher than current protein recommendations, on a body weight basis.[12]
- A protein intake moderately higher than current recommendations could provide health benefits for ageing populations.[18]
- For older people current recommendations tend not to account for compensatory loss of muscle mass that occurs on lower protein intakes.[19]

SECTION 2

Protein recommendations – are they getting dated?

The United Kingdom

In the UK, the Department of Health[11] published protein recommendations in 1991. These were based on estimates of the amounts of high-quality egg or milk protein needed for nitrogen equilibrium, determined from nitrogen balance studies mostly conducted in the 1970s.

Additions to baseline values were made for growth during childhood, pregnancy and lactation using estimates of the nitrogen content of tissue and rates of weight gain. RNIs for protein from this report are shown in Table 2, which are still used today within the latest Public Health England guidelines, published in 2016.

It should also be considered that RNIs were derived from standard weights at the time e.g. 60kg for a female aged 19-50 years. Today we know that bodyweights are significantly higher - females, for example, have an average body weight of 70.6kg.[c] Bearing this in mind **rising body weights could impact on protein requirements** nearly five decades on.

[c] https://www.onaverage.co.uk/body-averages/average-female-weight

Table 2: UK: Protein Intake Recommendations

Age	Weight (Kg)	Male	Female	Male	Female
		RNI (g/d)		g/kg-day*	
1-3yrs	12.5	14.5	14.5	1.16	1.16
4-6yrs	17.8	19.7	19.7	1.11	1.11
7-10yrs	28.3	28.3	28.3	1.0	1.0
11-14yrs	43.0 (M) 43.8 (F)	42.1	41.2	0.97	0.94
15-18yrs	64.5 (M) 55.5 (F)	55.2	45.4	0.86	0.82
19-50yrs	74.0 (M) 60.0 (F)	55.5	45.0	0.75	0.75
50yrs+	71.0 (M) 62.0 (F)	53.3	46.5	0.75	0.75
Pregnancy			+6		
Lactation (0-6 months)			+11		
Lactation (6+ months)			+8		

*Calculated. Source: DH (1991) pg78-84[11]; PHE (2016) pg 6.[20]

Europe

In 2012 the European Food Safety Authority (EFSA)[21] published population reference intakes (PRIs) for protein. The PRI is defined as the amount of an individual nutrient (in this case protein) that the majority of people in a population need for good health depending on their age and sex. The PRIs apply to mixed dietary protein from both animal and plant sources. The EFSA's Panel on Dietetic Products, Nutrition and Allergies PRIs for protein have been set as follows:

- ***Infants, children and adolescents*** – between 0.83g and 1.31g/kg-day depending on age.
- ***Adults*** (including older adults) – 0.83g/kg-day.
- ***Pregnant women*** – additional intake of 1g, 9g and 28g per day for the first, second and third trimesters respectively on top of requirements for adults.
- ***Breast-feeding women*** – additional intake of 19g per day during the first 6 months of lactation and 13g per day thereafter on top of requirements for adults.
- ***Tolerable Upper Intake Level*** – Data was insufficient so these could not be derived, though in adults an intake of twice the PRI was regarded as safe.

Again, the nitrogen balance approach was used to set PRIs for protein. The factorial method[d] was used to determine protein requirements for physiological conditions such as growth, pregnancy or lactation.

The panel did not derive reference values for indispensable amino acids since amino acids are not provided as individual nutrients but in the form of protein. The Panel concluded that further data is needed to sufficiently derive precise values for IDAA requirements.

Nordic Countries

The Nordic countries are considered to refer to Denmark, Finland, Iceland, Norway and Sweden, including their associated territories (Greenland, the Faroe Islands and the Åland Islands).[e]

The Nordic countries have collaborated to establish guidelines for recommended intakes of nutrients and compiled Nordic Nutrition Recommendations (NNR).[22,f]. The report uses nitrogen-balance to establish dietary protein recommendations but recognises that other methods have been developed. The guidelines use evidence from systematic reviews and meta-analysis papers including that from Rand *et al*. (2003)[23], Pederson *et al*. (2013)[24] and Pederson *et al*. (2014).[25] Main recommendations are as follows:

[d] https://www.efsa.europa.eu/en/press/news/120209
[e] https://www.worldatlas.com/articles/nordic-countries.html
[f] http://norden.diva-portal.org/smash/get/diva2:704251/FULLTEXT01.pdf pp281-309.

Adults and children from 2 years of age:

- Based on the available evidence, and according to the Nordic dietary habits, protein should provide 10–20% of the total energy intake.
- For food planning purposes with energy intake in the range of 8–12 MJ, an appropriate target is 15 E% and this corresponds to about 1.1g/kg-day'.

Elderly (≥65 years):

- Protein should provide 15–20 E%, and with decreasing energy intake (below 8 MJ/d) the protein E% should be increased accordingly.
- For food planning purposes, the recommendation is 18 E%, which corresponds to about 1.2 g protein/kg.

Upper intake levels: No upper intake level could be established based on limited evidence.

The United States

The 2002 United States recommendations from the Institute of Medicine[26 27] for protein were also based on the meta-analysis of nitrogen balance studies by Rand *et al*.(2003)[23] and cite an EAR of 0.66g/kg bodyweight per day and an RDA of 0.8g good-quality protein/kg-day. These have distinctly categorised age ranges and are summarised in Table 3 overleaf.

In relation to selected food sources the report states that: *"Proteins from animal sources, such as meat, poultry, fish, eggs, milk, cheese, and yogurt, provide all nine indispensable amino acids in adequate amounts, and for this reason are considered "complete proteins". Proteins from plants, legumes, grains, nuts, seeds, and vegetables tend to be deficient in one or more of the indispensable amino acids and are called 'incomplete proteins'. Vegan diets adequate in total protein content can be "complete" by combining sources of incomplete proteins which lack different indispensable amino acids".*

Australia.

Nutrient Reference Values for Australia and New Zealand are published by the Australia Government Department of Health and Ageing and the National Health and Medical Research Council.[28] They were originally compiled in 2006 and updated in September 2017.

The protein recommendations were compiled using evidence available at the time, which was mainly from nitrogen-balance studies. These protein recommendations are shown in Table 4 and include an EAR and Reference Dietary Intake (RDI). No Upper Limit was set as there was insufficient data.

Table 3: US Protein Dietary Reference Intakes

Life-Stage	RDA/AI g/d	*AMDR*
Children 1-3 years	13	5-20
Children 4-8 years	19	10-30
Males 9-13 years	34	10-30
Males 14-18 years	52	10-30
Males 19-30 years	56	10-35
Males 31-50 years	56	10-35
Males 50-70 years	56	10-35
Males > 70 years	56	10-35
Females 9-13 years	34	10-30
Females 14-18 years	46	10-30
Females 19-30 years	46	10-35
Females 31-50 years	46	10-35
Females 50-70 years	46	10-35
Females > 70 years	46	10-35

Key: AI, Adequate Intakes; RDA, Recommended Dietary Allowances. RDAs and AIs may both be used as goals for individual intake. RDAs are set to meet the needs of almost (97-98%) of individuals. AMDR, Acceptable Macronutrient Distribution Range. This is the range of intake for a particular energy source that is associated with reduced risk of chronic disease while providing intakes of essential nutrients.

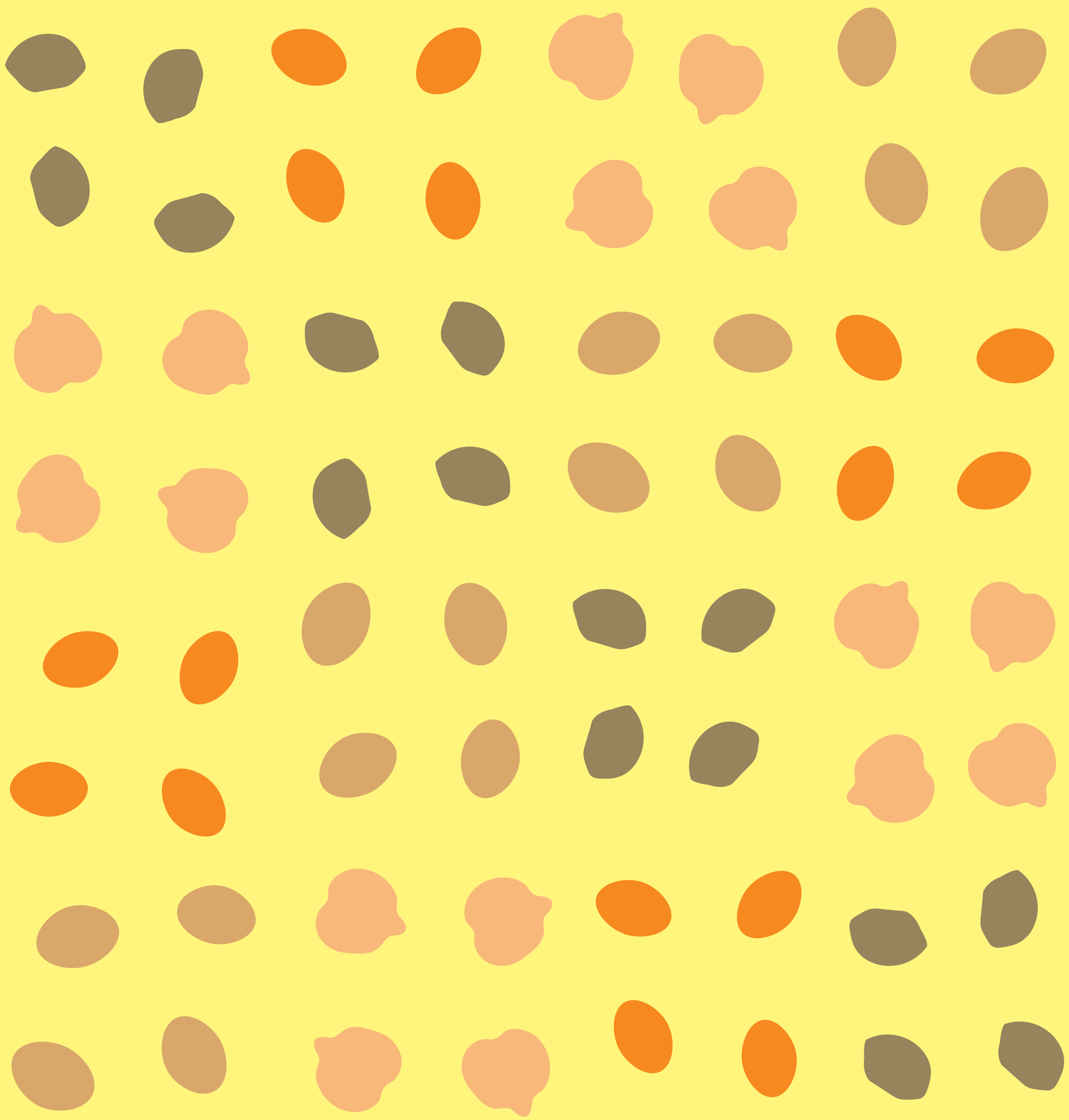
Table 4: Australia & New Zealand Protein Recommendations.

Age		Male		Female	
		g/day	g/kg	g/day	g/kg
1-3yrs		14	1.08	14	1.08
4-8yrs		20	0.91	20	0.91
9-13yrs		40	0.94	35	0.87
14-18yrs		65	0.99	45	0.77
19-30yrs	EAR	52	0.68	37	0.60
	RDI	64	0.84	46	0.75
31-50yrs	EAR	52	0.68	37	0.60
	RDI	64	0.84	46	0.75
51-70yrs	EAR	52	0.68	37	0.60
	RDI	64	0.84	46	0.75
>70yrs	EAR	65	0.86	46	0.75
	RDI	81	1.07	57	0.94

Source: NH MRC (2006; updated 2017).

SECTION 3

Protein sources – is there a need for a consensus?



A global review,[29] published in the American Society for Nutrition journal, analysed food-based dietary guidelines (FBDG) across 90 countries. It was found that whilst guidance to consume a variety of foods; to consume some foods in higher proportion than others; to consume fruits and vegetables, legumes, and animal-source foods; and to limit sugar, fat, and salt was nearly universal, guidelines on dairy, red meat, fats and oils, and nuts were more interchangeable.

This section evaluates FBDG in the United Kingdom, Europe, Nordic countries, Switzerland, United States, South Africa and Australia (Table 5) focusing on the protein element of these.

Table 5: Contrasting Food-based Protein Guidance

Country	Main advice	Reference point
United Kingdom	Eat some beans, pulses, fish, eggs, meat and other proteins (including 2 portions of fish every week, one of which should be oily). **Other vegetable-based sources of protein include tofu, bean curd and Mycoprotein;** all of which are widely available in most retailers.	Eatwell Guide
Europe Union	Beef and lamb, pork, chicken and other poultry, eggs, fish, legumes, dry beans, lentils, peas, soy foods, peanuts and tree nuts are listed within the healthy reference diet.	EAT-Lancet
Nordic Countries	Increase intakes of vegetables, pulses, fruits and berries, fish and seafood, nuts and seeds.	Nordic Nutrition Recommendations
Switzerland	Adults: Consume three portions of dairy products and also one portion of meat/fish/eggs/tofu per day. ***Alternate between these protein-rich foods.*** Children: Drink water. Eat Fruit and Vegetables. Make clever choices when it comes to food and drink. Turn your screen off when you eat.	Swiss Food Pyramid/ Swiss Children's Nutrition Disk
United States	***Vary your protein routine.***	MyPlate
South Africa	***Eat dry beans, split peas, lentils and soya regularly. Fish, chicken, lean meat or eggs can be eaten daily.***	Vorster *et al.* (2013)[30]
Australia	Enjoy a wide variety of nutritious foods including: **Lean meats and poultry, fish, eggs, tofu, nuts and seeds, and legumes/ beans.**	Eat for Health

The United Kingdom

In the UK a modified Eatwell Guide was published in 2016 by Public Health England.[g]

The guide was compiled to help people obtain 'a balance of healthier and more sustainable food'. The guide encompasses a sector listed as: *'Beans, pulses, fish, eggs, meat and other proteins'*. Although it is not clear what 'other proteins' constitutes on the main infographic in the main document this is reported to include tofu, bean curd and Mycoprotein.

It is anticipated that this segment in the future could display a greater array of protein food sources, including alternative plant-based proteins such as Mycoprotein, tofu, tempeh, edamame and beancurd, quinoa and seitan.

Europe

The recent Lancet-EAT report[8] has compiled a healthy reference diet, with possible ranges, for an intake of 2500kcal/day (Table 6). This report and advice focuses on diets of generally healthy adults' aged 2 years and over.

The healthy reference diet and protein levels within this report are based on the benchmarks that: *'adequate protein intakes for adults is 0.8g/kg bodyweight which is 56g/day for a 70-kg individual or 10% energy intake'*.

The EAT-Lancet diet resembles the Mediterranean diet – similar to that of Crete in the mid-20th century which was low in red-meat and poultry, mostly plant-based and abundant in olive oil - with Greeks having one of the longest life expectancies at that time.[31 32]

Nordic countries

Based on the scientific evidence documented in the 5th edition of the Nordic Nutrition Recommendations, an overall 'micronutrient-dense' dietary pattern and a set of food selection changes were identified to promote health and wellbeing in the Nordic populations.

Within the summary of dietary changes, it has been advised that intakes of red and processed meat should be limited yet exchanges for protein sources are not yet included. Equally, whilst it is mentioned that intakes of vegetables, pulses, fruits and berries, fish and seafood, nuts and seeds should be increased there is not yet a mention of alternative non-meat protein sources such as Mycoprotein, tofu or beancurd.

Switzerland

In Switzerland, the Swiss food pyramid was developed by the Swiss Society for Nutrition in collaboration with the Federal Office of Public Health and science/industry experts along with public consultation.[h] Whilst the Swiss food pyramid is directed at the 'healthy adult population' for children aged 5 to 12 years an adapted version of this known as the 'Swiss children's nutrition disk' has been compiled.

Protein Guidelines

Table 6: The EAT-Lancet Healthy reference diet with possible ranges, for an intake of 2500 kcal/day.

	Macronutrient intake (possible range) g/day	Caloric intake, kcal/day
Wholegrains		
Rice, wheat, corn, *and other*	232 (total grains 0-60% of energy)	811
Tubers or starchy vegetables		
Potatoes and cassava	50 (0-100)	39
Vegetables		
All vegetables	300 (200-600)	-
Dark green vegetables	100	20
Red and orange vegetables	100	30
Other vegetables	100	25
Fruits		
All fruit	200 (100-300)	126
Dairy foods		
Whole milk or derivative equivalents (eg cheese)	250 (0-500)	153
Protein sources		
Beef and lamb	7 (0-14)	15
Pork	7 (0-14)	15
Chicken and other poultry	29 (0-58)	62
Eggs	13 (0-25)	19
Fish	28 (0-100)	40
Legumes		
Dry beans, lentils and peas	50 (0-100)	172
Soy foods	25 (0-50)	112
Peanuts	20 (0-75)	142
Tree nuts	25	149
Added fats		
Palm oil	6.8 (0-6.8)	60
Unsaturated oils	40 (20-80)	354
Dairy fats (included in milk)	0	0
Lard or tallow	5 (0-5)	36
Added sugars		
All sweeteners	31 (0-31)	120

[g] https://www.gov.uk/government/publications/the-eatwell-guide
[h] http://www.fao.org/nutrition/education/food-based-dietary-guidelines/regions/countries/switzerland/en/

Within the Children's Nutrition Disk specific guidance relating to protein consumption is lacking. It is possible that some of the advice for adults could be translated across to children. Adult guidance to 'consume three portions of dairy products and also one portion of meat/fish/eggs/tofu per day' could be extended to include other plant-based sources of protein and Mycoprotein.

The United States

The United States Department of Agriculture compiled the 2015-2020 Dietary Guidelines[33] and MyPlate.[i] Within the Dietary Guidelines for Americans it is recommended that adults eat ***"A variety of protein foods**, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products".*

A health style eating pattern also included protein foods in the following proportions: Protein Foods 5½oz-eq/day, Seafood 8 oz-eq/wk, Meats, Poultry, Eggs 26oz-eq/wk and Nuts, Seeds, Soy Products 5oz-eq/wk. The *Dietary Guidelines for Americans* is updated every five years. The process of developing the 2020-2025 edition of the *Dietary Guidelines* appears to be in progress.[j] When updating these, the addition of other protein sources such as Mycoprotein, tofu and insects would be worthy of consideration.

South Africa

South Africa published FBDG in 2013.[30] These are largely based on the belief that *"people eat foods and not nutrients"* which led to scientists replacing nutrient-based recommendations for the public with FBDG.

Advice in relation to protein consumption includes eating lean meat, fish or eggs, dry beans, split peas, lentils and soya but Mycoprotein and other alternative protein sources are overlooked.

Australia

Australian Dietary Guidelines[k] protein guidance includes enjoying a wide variety of: Lean meats and poultry, fish, eggs, tofu, nuts and seeds, and legumes/beans.

The report[34] also provides guidelines on the number of protein servings consumed each day, with a portion or 'serve' being carefully defined. For example, a female aged 19 to 60 years requires 2.5 serves of protein daily. This would constitute 2 large eggs, 190g tofu and 30g nut, seeds or nut butter. Once again alternative plant-based sources of protein, such as Mycoprotein, appear to have been overlooked.

[i] https://www.choosemyplate.gov/dietary-guidelines
[j] https://www.dietaryguidelines.gov/
[k] https://www.eatforhealth.gov.au/guidelines/australian-dietary-guidelines-1-5

SECTION 4

How much protein are we eating?

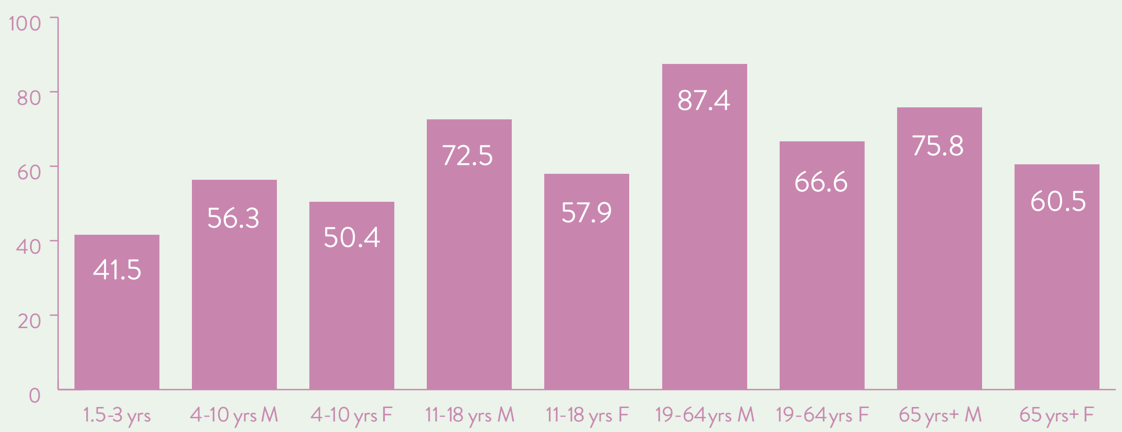
In general, protein intakes are higher than intake recommendations. However, **some populations could become vulnerable to protein shortfalls should protein requirements be updated and increased.**

Data from the UK National Diet and Nutrition Survey (NDNS)[35] shows that protein intakes are variable across the life span (Figure 1). Gender differences are apparent, which begin early on in childhood with boys aged 4 to 10 years having higher protein intakes than girls of the same age. The trend towards males having higher protein intakes remains apparent across the lifespan. Overall, usual protein intakes in the UK exceed intake recommendations across the ages.

In the United States National Health and Nutrition Examination Survey (NHANES) data shows similar trends.[36] Data collated from 2001-2014 showed **that protein comprised 14-16% of total energy** with intakes being above the EAR in all demographic groups. For adults' **protein intakes averaged out at 1.1g/kg-day.** Teenagers (14-18 years), females and older adults (≥71 years) were vulnerable to protein shortfalls.

Overall, it was concluded that protein intakes remained well below the upper end of the Acceptable Macronutrient Distribution Range meaning that **protein intakes, as a percentage of energy intakes are not excessive in the American diet.**

Figure 1: Protein Intakes (g/day) in the UK
Source: NDNS (2018) Data from Years 7-8[1]



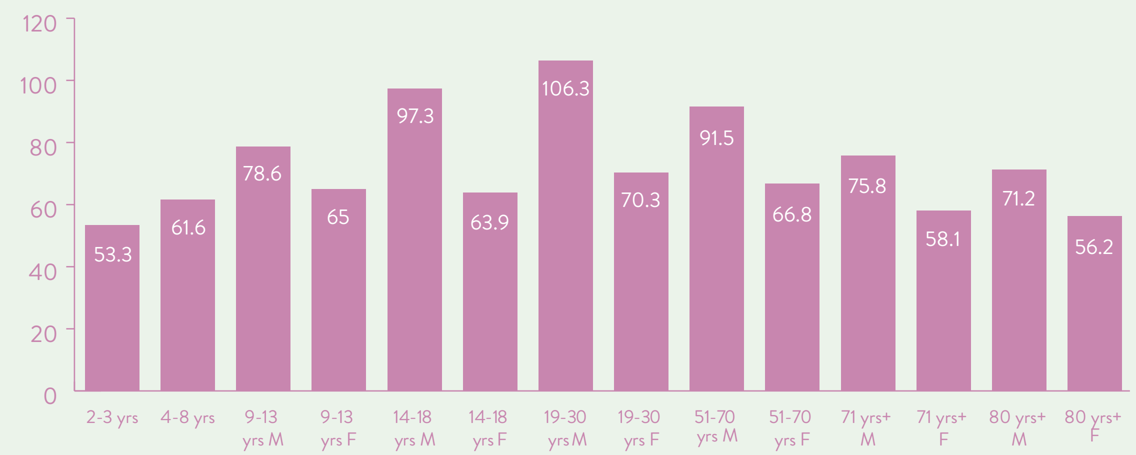
[1]https://www.gov.uk/government/statistics/ndns-results-from-years-7-and-8-combined Data plotted from Table 3.2.

Plant-based diets as a protein provider. Some interesting work has modelled the effects of increasing intakes of plant-based foods on protein intakes. The study[37] used NHANES data and focused in on the diets of older Americans.

Interestingly, it was found that **doubling intakes of plant-based foods (legumes, nuts, seeds and soy) resulted in a 22% decline in protein intakes amongst men and women aged 51 years and over.**

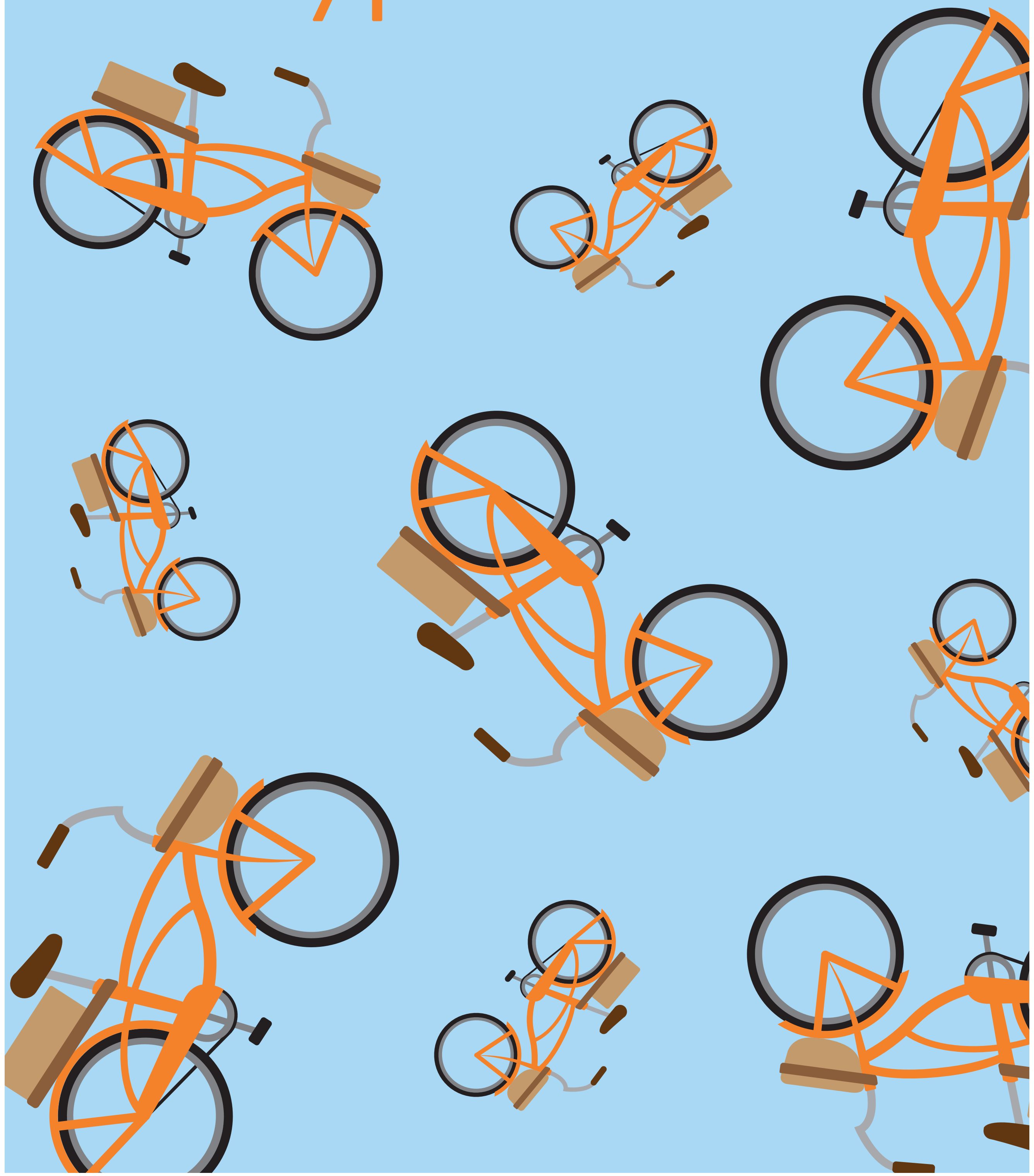
These findings demonstrate that **the definition of 'plant-based' could be in need of refinement**. If this was to include other bioavailable and non-animal derived protein sources, such as Mycoprotein, such reductions in protein intakes could be prevented.[38] The study by Houchins *et al.* (2017)[37] also found that doubling dairy intakes helped to achieve protein intakes of 1.2g/kg body weight, which is more closely in line with recommendations.

Figure 2: Protein Intakes (g/day) in the US
Source: NHANES (2001-2014).[36]



SECTION 5

What are our main sources of dietary protein?



In the United Kingdom[35] meat and meat products contribute to around one-third of daily protein (37%) (Figure 3). Cereals provide around a quarter (23%) of daily protein followed by milk and milk products, which contribute to just over a tenth (13%) of daily protein intakes. Fish, vegetables and potatoes provide 7-8% of daily protein. Eggs, nuts and seeds, fruit and savoury snacks all provide less than 5% of daily protein.

Data from the NHANES (2007-2010)[39] has determined mean intakes of animal, dairy and plant protein. Plant protein foods included: *yeast breads, rolls and buns, nuts and seeds, pasta dishes, beans, peas, legumes, French fries and white potatoes, tortilla, beer, cookies, ready-to-eat cereals, rice, cakes and pies, bagels and soups, indicating the broadness of the definition.*

As shown in Figure 4 animal protein provided 46% of total protein intakes followed by plant protein – 30% and dairy at 16%. Chicken and beef were the main food sources of animal protein intake. Yeast breads, rolls/buns, and nuts/seeds were predominant sources of plant protein intake and cheese, reduced-fat milk, and ice cream/dairy desserts were the main sources of dairy protein intake.

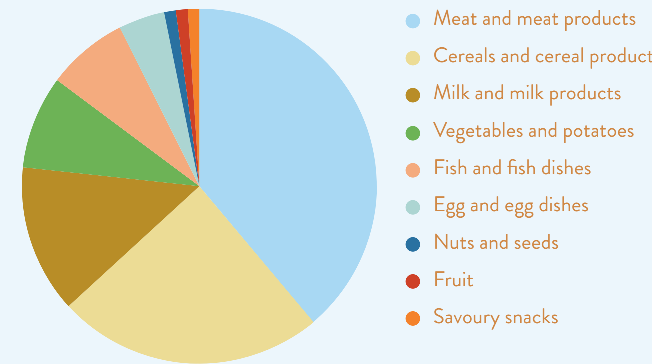


Figure 3: Percentage contribution of food groups to average daily protein intakes.

Source: NDNS (2018) Data extrapolated from Table 6.2 for adults aged 19-64 years.

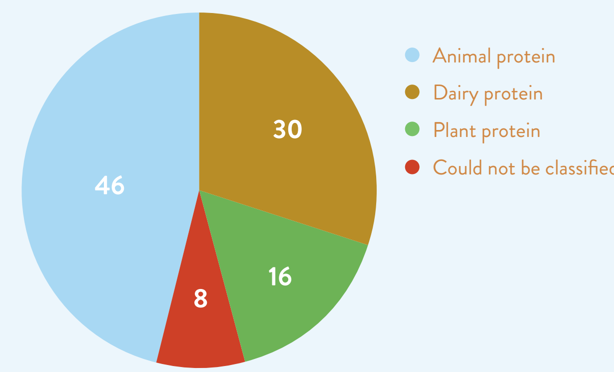


Figure 4: Amounts of Animal, Dairy and Plant Protein in US Adults

Source: NHANES (2007-2010)[39]

In Switzerland[40] an evaluation of protein intakes form food consumption data showed that two-thirds of proteins consumed were animal proteins [meat and meat products (28%)], followed by milk and dairy products (28%), fish (3%), and eggs (3%)] and around one-third of proteins were plant origin (25% of cereals, 3 - 4% of vegetables). Most of the population were within protein recommendations (10-20% of energy) with the frail elderly being most at risk of not covering their protein requirements.

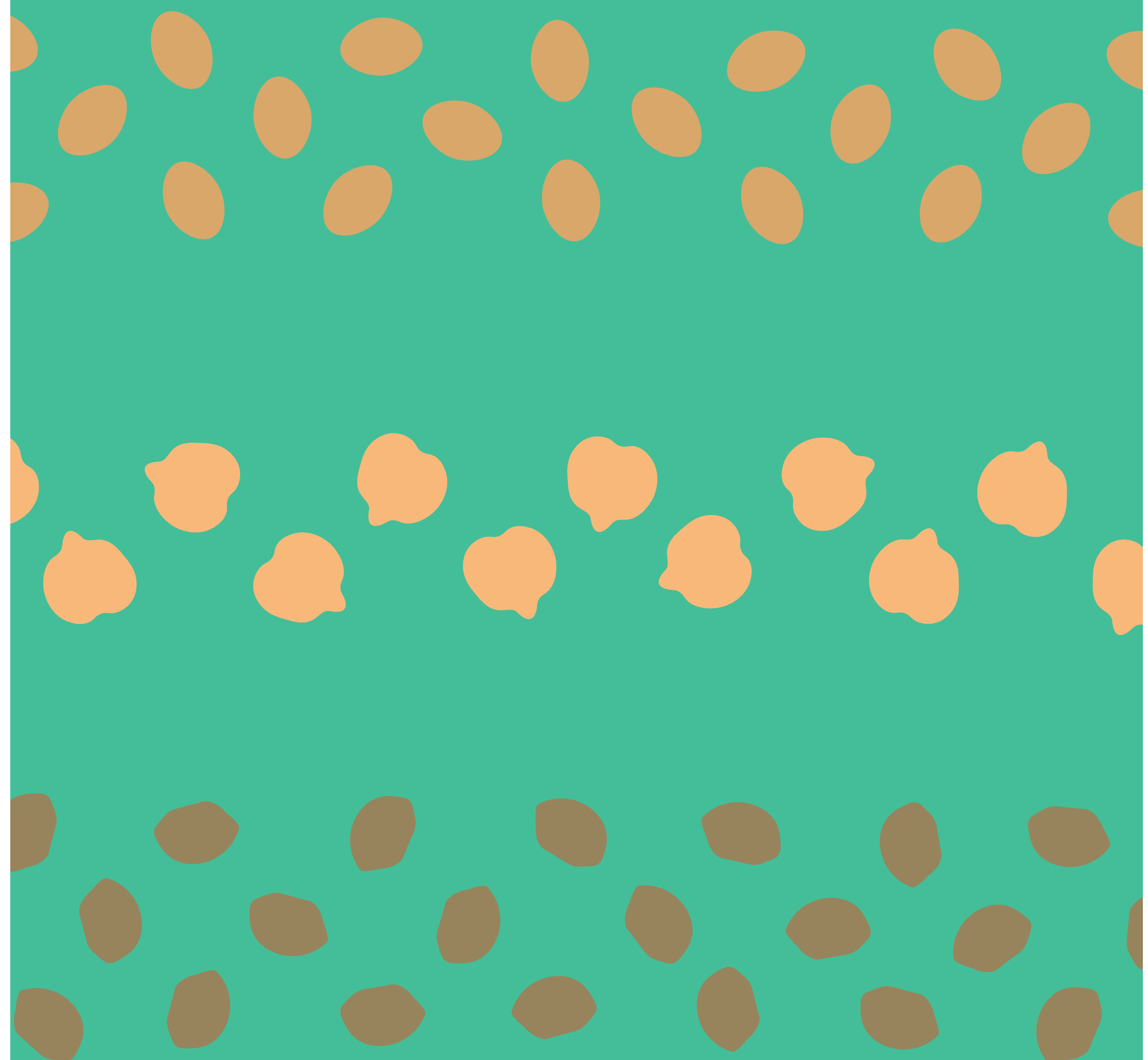
In an older Dutch population[41] daily protein intakes were 71g in community-dwelling and frail adults and just 58 g in institutionalised elders. Dietary protein intake ranged from 10 to 12g at breakfast, 15 to 23g at lunch and 24 to 31g at dinner, together contributing over 80% of daily protein intake. Most protein was derived from animal sources (≥60%) during the main dinner. Plant-based protein provided 40% of the protein intake in community-dwelling, 37% in frail and 29% in institutionalised elderly, with bread being the predominant source.

Overarching points:

- **Overall, plant protein appears to be providing around one-third of dietary protein** in Western regions. Although, it is possible that intakes could be even higher than this, as protein contributions from foods may have shifted since surveys were analysed.
- **The definition of 'plant-based' appears to be in need of refinement.** In some research[39] this encompasses the likes of French-fries, cakes and pies yet excludes the bioavailable[38] non-animal derived proteins like Mycoprotein.
- **As dietary protein trends shift dietary surveys need to better account for such movements.** For example, regrouping of protein categories to include a wider range of food-derived protein sources will become increasingly important.

SECTION 6

Protein – all in the timing?



Daily protein intakes are important to treat age-related declines in muscle mass and strength. Increasingly, it is coming to light that **the timing of protein consumption is important too**. A new pool of thought is that protein intake on a per-meal basis could be considered rather than focusing on daily intakes alone.[42] For example, eating moderate amounts of high-quality protein at each meal could optimise 24-hour muscle protein synthesis.[18] In this section we have summarised some of the latest science in this field.

Skewed protein timings in teens – An analysis of data from 2532 children and teenagers (4-18 years) providing 24-hour dietary recalls as part of the National Health and Nutrition Examination Survey showed that amongst those aged 14-18 years 20% had their first eating occasion after 11am and 34% had their last eating occasion at 9pm.[43] These results show that protein (and energy) intakes were skewed towards the evening. The ramifications of this now warrants further study.

Uneven protein distribution in elders – a risk factor for sarcopenia? - Other work[44] has monitored protein distribution in older adults. Research at the University of Birmingham found that average protein intakes were 1.14g/kg^{-1}/day[1] amongst 38 subjects with a mean age of 78 years. Distribution for meals was uneven with 79% reporting <0.4g/kg-day protein content in at least 2/3 daily meals. It was concluded that this could pose a risk factor for sarcopenia. Ongoing research is needed.

Protein ingestion before sleep could preserve elders muscle mass – A review published in *Frontiers in Nutrition*[45] concludes that the ingestion of protein before going to bed (sleep) is more likely to be digested and absorbed effectively, thus increasing overnight muscle protein synthesis.

Furthermore, this also appears to be beneficial when applied over a prolonged period of resistance-type exercise training, helping to increase muscle mass and strength. Ongoing research is needed, but these logical findings appear to be a promising means of improving muscle protein synthesis rates.

Even protein distribution could boost grip strength? – Data from years 2011-14 of the NHANES[46] have now been analysed to look at protein intakes 'per eating occasion'. This analysis revealed that only 33% of men and 19% of women had protein intake of ≥25g at two or more eating occasions. In turn, higher daily protein intakes were positively associated with grip strength, but only in women. Ongoing research looking at protein per eating occasion is warranted.

SECTION 7

Alternative protein sources

Growing populations, prolonged lifespans and economic prosperity are collectively exacerbating global demands for meat and dairy – demands resulting in intensification and unsuitable production of livestock.[47,48] Subsequently, to relieve such strains alternative protein sources need to be better utilised. Here we discuss and provide some examples.

Mycoprotein - Mycoprotein first came about in the early 1960s when the British Industrialist Lord Rank sought to find a new, safe and alternative source of protein that could be used to offset the global food crisis, which was also driven by population growth.[49] By 1967 Lord Rank and the Rank Hovis McDougall group had tested more than 3,000 soil organism samples from across the world and identified *Fusarium venenatum* from a garden in Marlow, Buckinghamshire in the United Kingdom[49]. Scientists discovered that this aerobic micro fungus could convert carbohydrate into protein – a process that could be applied on a larger scale to produce food-grade protein, today known as Mycoprotein.

From a nutritional perspective, Mycoprotein is particularly unusual in that is has a low energy, fat and high fibre profile, which makes it an ideal healthy protein source.[50] Mycoprotein contains all nine essential amino acids (essential in that they must be obtained through the diet as the body cannot produce them), which have been found to be bioavailable and insulinotropic making it a useful protein for the stimulation of muscle protein synthesis.[38,51,52] Together, this makes Mycoprotein a high-quality protein that could help provide a balanced plant-based eating style.

Soy protein - Soy proteins became popular in the 1990s - made by dehulling, flaking and defatting soybeans – soy milk and tofu are some of the dried soyfoods that can be produced.[53] Soybean provide abundant amounts of isoflavones but whilst these could protect against certain chronic diseases they are still not without controversy – with some uncertainties about their suitability for consumption by children and young people.[54]

Insects – Insects have potential to be produced on a viable and sustainable commercial scale, thus could be a suitable alternative source of dietary protein.[55] Their consumption is not that infrequent, where in tropical regions more than 2000 insect species are eaten. They appear to have the same protein content as meat and a better polyunsaturated fatty acid profile.[56] Further work is needed to make these a viable sector, including understanding consumer perceptions and atittudes.

Lupins, quinoa and hempseed - Lupins, quinoa and hempseed provide energy, high quality proteins, fibre, vitamins and minerals, polyphenols and bioactive peptides.[7] Further work is needed to study these as the right combinations of such plant proteins could provide suitable amounts of essential amino acids for human requirements.

***In Vitro* (Lab) Meat** – NASA (National Aeronautics and Space Administration) originally initiated research on in *vitro* meat consumption for space travel.[57] This biofabrication approach involves the use of skeletal muscle tissue engineering, stem cell, co-culture and tissue culture methods, and has the scope to mimic conventional meat qualities.[57]

A great deal of ongoing research is needed to translate such animal-free culture systems into methods that could be adopted on an industrial scale and translated into a real life scenario.[58]

Thus, when considering 'plant-based' diets there are a range of established and emerging protein sources that have potential to be embedded within this shifting dietary lifestyle. For foods that do not fit into this category another definition such as 'alternative proteins' may be required.

SECTION 8

Protein quality redefined

It has been recognised that **the current definition of protein quality is obsolete, inaccurate and potential harmful to public and planetary health.** Prevailing definitions have been based on the ability of a dietary protein to meet needs for regular metabolism and maintenance or growth of body tissues with 'protein quality' metrics being based on the essential amino acid profiles in foods and their digestibility.[59 60]

Yet the word 'quality' is misleading – implying superiority typically from animal protein sources whilst high intakes could impact on public and environmental health. Thus, this outdated definition does not encompass the 'net health effect' of protein foods and is at odds with contemporary movements to produce and eat foods in a sustainable fashion.

Updated research published in *Advances in Nutrition*[2] and authored by five leading scientists redefines protein quality based on updated scientific literature. The new definition has been compiled into a metric that can now be applied to national and food regulatory labelling systems. The most recent definition on protein quality now includes:

- The concentration of protein and individual amino acids in the food.
- An assessment of the evidence of health outcomes associated with consumption of the food.
- An assessment of potential environmental impacts of producing the food.

This more rounded approach will also help scientists and consumers alike to better recognise the value of plant proteins and allow people to eat for their own health and the health of the environment.

Plant-based inclusions

In modern day the real reality is that the risk of protein inadequacy is low in developed regions such as the United States.[36] As almost true of any dietary pattern when a variety of plant sources are eaten in sufficient amounts the needs for essential amino acids can be met even without any animal protein intake.[61]

In an everyday sense people do not tend to eat protein independent of other food sources. Diets are typically mixed with an array of sources of protein, all with different amino acid profiles. Therefore, it is the amino acid composition of the 'overall' diet that will determine protein adequacy.[2] Subsequently, the rationale for defining protein quality based on the essential amino acid profile of an 'individual food' is questionable, especially when applying this to populations in developed countries.

Alongside this, ongoing research is needed. It is still very premature to use animal versus plant as categories of protein and draw robust conclusions as to how the body handles these large groupings without a lot more data. Even regarding protein from animal sources minimal data have looked at whole foods, animal proteins within a mixed meal and various types of meat.

Bioavailability of Mycoprotein

Research has now moved on and looked at the bioavailability of non-animal-derived protein sources, including Mycoprotein.

After a series of five trials[38] it was concluded that the ingestion of 40g mycoprotein (i.e. 18g total protein) would be sufficient to mount a robust muscle protein synthetic response, with the ingestion of 60g mycoprotein (i.e. 27g total protein) likely necessary to provide an optimal anabolic response. Mycoprotein also resulted in slower and more sustained hyperaminoacidaemia (higher fasting levels of amino acids in the bloodstream) compared with controls.

Overall, it was concluded that Mycoprotein was a bioavailable protein that could stimulate muscle protein synthesis rates without being derived from animal sources. It is possible that these effects could have been attributed to the favourable leucine profile of Mycoprotein – a 60g bolus provides close to what is considered the optimal leucine content to facilitate a maximal muscle protein synthetic response (i.e. ≥2·5g).[62-64]

SECTION 9

A focus on Mycoprotein

In recent years a growing body of work has suggested that protein intakes above current guidelines could assist with healthy ageing - including the prevention of sarcopenia and loss of muscle mass linked to frailty, appetite regulation, weight management, and goals associated with athletic performance.[10] As discussed in Section 2, protein intakes of at least 1.2 to 1.6g/kg-day could be a more realistic estimate to achieve optimal health.[10]

One pending question is how can this be achieved? The movement away from animal-protein and an extra protein increment could leave an impending gap between intakes and thresholds needed for health. Alternative protein sources will therefore have an important role to play in helping to plug such gaps in the future. This section focuses on the role of Mycoprotein.

Nutritional Profile

Mycoprotein when compared against European Commission, nutrition claims[65,66] may be categorised as being:

- ***'high in protein'*** (at least 20% of the energy value of the food is provided by protein)
- ***'low in fat'*** (it contains no more than 3g of fat per 100g of solids)
- ***'low in saturated fat'*** (it does not contain more than 1.5g of saturated fatty acids per 100g of solids)
- ***'high in fibre'*** (it contains at least 6g of fibre per 100g)

As shown in Table 8, Mycoprotein provides an array of vitamins and minerals, including calcium, magnesium, potassium, phosphorous, selenium and chromium. Compared with other protein sources it is low in energy and fat, whilst being a good provider of dietary fibre. It is also low in sodium and contains only neglible amounts of cholesterol. Ongoing data on the nutritional composition of alternative proteins is needed. For insects', data was only available for a 'cricket flour protein bar', which may explain its higher energy and calcium profile.

Table 7: Nutritional Profile of Various Protein Sources

	Mycoprotein[3]	Red Meat[4]	Chicken[5]	Tofu[6]	Insects[7]
Nutrient	Amount per 100g[1]				
Energy (kcals)	85	312	107	88	500
Protein (g)	11	16.1	23.2	9.9	16.7
Carbohydrate (g)	3	0	0.89	2.2	38.3
of which sugars (g)	0.5	0	0	-	-
Fat (g)	2.9	26.8	1.3	4.4	33.3
of which saturates (g)	0.7	10.7	0	0.6	7.5
w-3 Linolenic acid (g)	0.4	-	-	-	-
fibre (g)	6[2]	0	0	2.2 (Total)	11.7 (Total)
b-glucan (g)	4	-	-	-	-
Calcium (mg)	42.5	0	0	132	167
Magnesium (mg)	45	-	-	-	-
Zinc (mg)	9	-	-	-	-
Iron (mg)	0.5	1.6	0.64	1.1	3
Potassium (mg)	100	-	-	132	-
Vitamin B1 Thiamin (mg)	0.01	-	-	-	-
Vitamin B2 Riboflavin (mg)	0.23	-	-	-	-
Vitamin B3 Niacin (mg)	0.35	-	-	-	-
Vitamin B5 Panotothenic acid (mg)	0.25	-	-	-	-
Vitamin B6 Pyridoxine (mg)	0.125	-	-	-	-
Biotin (mg)	0.02	-	-	-	-
Phosphorus (mg)	260	-	-	-	-
Copper (mg)	0.5	-	-	-	-
Manganese (mg)	6	-	-	-	-
Selenium (ug)	20	-	-	-	-
Chromium (ug)	15	-	-	-	-
Molybdenum (ug)	<25	-	-	-	-
Sodium (mg)	5	67	45	0	75
Choleseterol (mg)	N	85	62	0	17

N, negligible; [1]Wet weight; ie as consumed. For conversion to dry weight, multiply by 4; [2]AOAC method used; [3]data from Mycoprotein.org[52]; [4]Certified Angus beef, ground UPC: 076338422333; [5]Chicken breast, ground UPC: 03003407468; [6]Firm Tofu UPC: 692623018175; [7]Cricket flour protein bar UPC: 86170300007. Data from USDA database.

Protein Guidelines

Links with Health

Muscle protein synthesis

Research has assessed the bioavailability and insulinotropic effects of Mycoprotein.[38] The trial carried out at the University of Exeter recruited 15 healthy men who were asked to consume Mycoprotein in a dose-response manner.

It was found that 40g Mycoprotein (i.e. 18g total protein) was sufficient to stimulate a muscle protein synthesis response, whilst 60g Mycoprotein (i.e. 27g total protein) was considered ample to stimulate optimal muscle protein synthesis rates in healthy young men[38].

These important findings highlight Mycoprotein as a bioavailable and insulinotropic protein source that could stimulate muscle protein synthesis.[38] Investigators are continuing research in this field.

Metabolic & cholesterol profile

Several studies have investigated how Mycoprotein affects metabolic health and cholesterol profiles.[50] [67-71] In an early trial cookies providing 20g *Fusarium venenatum* improved cholesterol levels amongst 100 adults studied.[71] Other work found that Mycoprotein in the form of cookies (26.9g dry weight/d; 130g Quorn™ at normal moisture content) significantly reduced plasma cholesterol by 13%, LDL cholesterol by 9% and increased HDL cholesterol by 12% compared with the control diet.[69] Ishikawa *et al.* (1994) showed that subjects with elevated cholesterol levels were most likely to benefit from Mycoprotein consumption[68] and another study found that 88g of wet weight Mycoprotein daily (dry weight equivalent to 21g Quorn™) over six weeks significantly reduced total and LDL cholesterol, particularly amongst those with higher baseline blood cholesterol levels (≥4.19mmol/L).[67] Improved cholesterol profiles could be due to the fact that Mycoprotein does not contain cholesterol.

Other studies have noted improvements in markers of glycaemia and insulinaemia[38] [72-74] One trial allocating healthy adults (n=19) to drink a ≈330ml milkshake containing 20g Mycoprotein or no Mycoprotein in the control milkshake showed that the Mycoprotein shake resulted in a 13% reduction in glycaemia 60 minutes after its consumption.[74]

Further work[72] has found that different doses of Mycoprotein (44, 88 and 132g) significantly reduce 24-hour insulin levels compared with chicken controls (closely matched for energy and macronutrient content) when eaten by overweight and obese volunteers. Other work by the same team showed that 30g Mycoprotein from a soup significantly reduced insulin levels at 15, 30 and 45 minutes following ingestion when compared with a whey protein control.[73] Research from 12 healthy young men given a test drink providing 20g milk protein or a mass matched bolus of Mycoprotein (20, 40, 60, 80g) found that Mycoprotein ingestion led to slower but more sustained hyperinsulinaemia and hyperaminoacidemia compared with milk when measured during a 4-h postprandial period with these effects appearing to plateau with the 60-80g bolus.[38]

Satiety & energy intake

Several trials have observed reduced energy intakes or satiety effects after Mycoprotein ingestion.[72] [75-78] Research from 18 lean healthy adults showed that Mycoprotein, when eaten as a part of a meal and providing 11g fibre, reduced evening energy intakes by 18%, indicating satiety effects.[77] Another trial with 13 healthy females showed that 130g Mycoprotein reduced energy intake on the day of the study (by 24%) and the next day (by 17%).[78]

Research from 43 overweight females (mean BMI 27.4) who ate three laboratory meals (220g pasta with chicken, tofu or Mycoprotein) over three test days found that food intakes were lower after Mycoprotein and tofu preloads.[76] Similarly a trial with 35 overweight adults eating 32g protein from isocaloric Mycoprotein or chicken meals showed that lunchtime energy intakes were also significantly lower after earlier Mycoprotein ingestion.[75]

SECTION 10

Protein – from a sustainability perspective

Defining sustainability

Truly defining what is meant by a sustainable diet is difficult, and there is currently no consensus. The word sustainable itself is used in a number of ways, and there is generally accepted to be three broad 'pillars' of sustainability; 1) economic, 2) social and 3) environmental.[79] All three are important when considering overall sustainability.

The official definition of a sustainable diet from the Food and Agriculture Organisation (FAO) of the United Nations, is: ***"Sustainable Diets are those diets with low environmental impacts, which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy while optimizing natural and human resources"***.[80]

This definition defines sustainable diets in broad terms but it is often criticised for its complexity. Positively however, this definition does encompass the nutritional adequacy of a diet for health.

A further definition from Fischer and Garnett at the Environmental Change Unit at the University of Oxford, often considered to be more practical, is simply that sustainable diets are *"low environmental impact diets consistent with good health"*.[81] Further complexity is added by the fact that environmental sustainability can include several criteria, including greenhouse gas emissions (GHGEs), land and water use, biodiversity, soil quality and so on.

Why does sustainability matter?

Diets have a considerable impact on the environment and current and projected diets are jeopardising the future security of the planet. The current food system contributes 20-30% of global GHGEs and therefore contributes significantly to global warming.[82] Agriculture and livestock farming are by far the biggest contributors to GHGEs, deforestation, biodiversity loss, and soil pollution, as well as land and water use.

GHG contributions from animal agriculture are particularly significant, contributing to 14.5% of human-made (anthropogenic) global GHGEs[83], including methane (from enteric fermentation in ruminants such as cows and sheep and from manure), nitrous oxide (from animal dung and urine and soils) and carbon dioxide (use of fossil fuels, deforestation, animal feed production, land use change).

Our appetite for more and cheaper meat is driving increased use of fertilisers and pesticides, with concerns that this is reducing biodiversity. In addition, whilst some nations are working to restrict and control the use of antibiotics as growth promoters in the production of meat, their widespread use is causing concern about an increase in antibiotic resistant bacteria and the return of pandemic disease in humans.[84] Antimicrobial resistance could, in turn, make mass animal farming impossible. With intensive livestock production and extreme pressure on supply chain costs comes growing concerns over animal welfare powerfully described in a book by Lymbery of Compassion In World Farming (CIWF) in an investigation into the true costs of cheap meat.

A projected world population of 10 billion by 2050 and increasing affluence means that global demand for food will increase, particularly meat consumption, which is projected to double.[82] Growing competition for land, water, and energy, in addition to the overexploitation of fisheries, will affect our ability to produce food, as will the urgent requirement to reduce the impact of the food system on the environment.

Protein sustainability

In this context of population growth, cultural change, increasing affluence and the environmental impact of animal food, but with the need for a healthy nutritious diet containing sufficient protein, increasing supply and diversity of alternative, complete protein options will be needed. **The world's over-reliance on livestock, particularly factory-farmed livestock, to meet the growing global demand for protein is unsustainable.**[85]

Shifting global demand for animal protein is central to achieving climate goals and both consumption and production need to change. The 2015 Paris Climate Agreement™ commitments to keep global temperature rise within safe limits cannot be met without including dietary change as a priority solution. Moderating meat and dairy intake is key for a more sustainable diet and has the potential to ensure a fair and secure livelihood for farmers and producers, more ethical and humane farming methods and better health outcomes.

Governments, non-governmental organisations (NGOs) and companies are starting to act. Both the Netherlands and China have issued policies calling for significant reductions in meat consumption by their populations, whilst the UK Eatwell Guide recommends a shift towards more plant-based protein and shows an appreciably lower environmental impact than the current UK diet.[86]

NGOs such as Eating Better Alliance and the World Wildlife Fund (WWF) have also made progress in addressing what a sustainable diet looks like with a "less but better" approach to meat eating. The British Dietetic Association (BDA) has produced policy and a resource document - *One Blue Dot* - to support dietitians in giving consistent messages about a healthy, sustainable, varied diet based on plants.[87] The Eat-Lancet Commission on Food, Planet, Health brought together more than 30 world-leading scientists to reach consensus on what constitutes a healthy, sustainable diet,[8] with the need to increase plant protein and reduce animal foods, not only for the benefit of the environment but also for public health.

Companies are being challenged to produce non-animal sources of protein with initiatives to date including products containing Mycoprotein, cultured meat, tofu/soya beans, algae, jackfruit, peas and beans, haem, insects, nuts and wheat-gluten/seitan.

Every week, celebrities are endorsing the need to consider what we eat in the context of combating climate change and consumer research indicates that 40% of meat eaters are aiming to reduce their meat consumption.[88] Research into the motivations that are shifting the dietary behaviour and meat consumption of UK consumers showed concerns over animal welfare as the number one reason for considering change.[89]

Plant-based protein sources and why these are more sustainable

Compared to animal sourced protein, plant protein sources offer a lower environmental impact and a more sustainable solution by reducing energy consumption, emissions, land usage, and water consumption.

Producers must feed plant protein to animals to produce animal proteins, and animals are not efficient converters, weight for weight, of the proteins they consume. On the basis of a per tonne of protein produced, production of animal-based foods accounted for more than three-quarters of global agricultural land use and around two-thirds of agriculture's production-related GHGEs in 2009, while only contributing 37% of total protein consumed by people in that year.[90] Beef is one of the least efficient foods to produce when considered from a "feed input to food output" perspective. According to one estimate, only 4% of ingested cattle protein is converted to human-edible protein, respectively.

Work by the Carbon Trust[91] has assessed the social (health and well-being), economic (household food prices) and environmental (climate, land and water) sustainability impact of a range of protein choices for the UK diet (Table 9). **In comparison with animal proteins and fish, plant protein sources were generally more sustainable. Mycoprotein, in particular, was shown to have a positive impact across all three metrics.**

Table 8: The social, economic and environmental sustainability impacts of proteins from the current average UK diet (from Carbon Trust 2014[91])

	Social impact (health & wellbeing)	Economic impact (household food prices)	Environmental impact (climate, land & water)
Fresh meat			
Processed meat	Too much salt		
Dairy	Need more Calcium		
Eggs			
Fish & seafood	Need more in our diet†		Avoid over-fishing*
Whole grains & pulses	Need more in our diet†		
Nuts & seeds	Need more in our diet†		
Tofu			Avoid deforestation‡
Mycoprotein			
Insect protein			
Lab grown meat			

Key	Low impact	Medium impact	High impact	Unknown

Mycoprotein and why this is more sustainable

Mycoprotein is a protein derived from fermentation of the filamentous fungus *Fusarium venenatum*, which is most commonly recognised as the main ingredient of Quorn™ products.

Mycoprotein has distinct environmental benefits. Producing protein through fermentation is more efficient and more sustainable than animal protein. The production of Mycoprotein simply takes the carbohydrate from the grain and converts it to protein, without the need for animals. In addition, the original grain protein remains available, such that the process increases the overall protein balance.[92]

Further research has established the wider environmental impacts of Quorn™ products, assessing not only the embedded GHG emissions associated with the products but also the water and land use footprints associated with Quorn™ Foods' supply chain. Recent publications[92,93] show that:

In comparison with beef:

- The product carbon footprint of Mycoprotein can be considered to be at least 10 times lower than that of beef.
- The water footprint of Mycoprotein is 20 times lower than that of beef (global average). Available data reveals that one kilogram of beef requires between 15,000 – 20,000 litres of water to produce, whilst the equivalent figure for Quorn™ Mince, for example, would be a fraction of that – at just under 2,000 litres per kilogram.[88]
- The land use of Mycoprotein is up to 10 times lower than for beef.

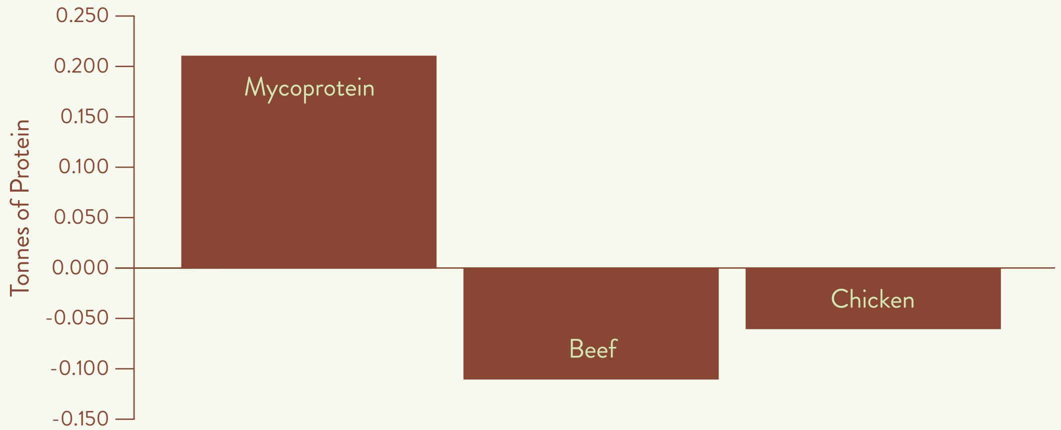
In comparison with chicken:

- The product carbon footprint of Mycoprotein can be considered to be at least 4 times lower than that of chicken.
- The water footprint of Mycoprotein is 6 times lower than that of chicken.
- The land use is at least twice as low as that for producing chicken.

If you cooked with Quorn mince instead of beef mince once a week for a year you'd save enough energy to boil approx. 20,000 kettles... the equivalent to around 1,800 cups of tea each week![93]

Overall, the production of meat is inefficient with huge amounts of grain and crops being used to feed humans when they could be used to feed livestock. A number of studies have shown that between 12-24kg of feed are required to produce 1kg of edible beef.[86 87] Poultry has a higher conversion efficiency but typically requires 2-4kg and in both cases more protein is fed to the animal than is actually produced.[88] Feed conversion ratios for Mycoprotein are more favourable, with under 2kg of wheat needed to produce 1kg of Mycoprotein – in comparison to beef (taking 12-24kg).[89] (Figure 4).

Figure 5: Protein yield of Mycoprotein, beef and chicken per tonne of wheat.



The Carbon Trust has certified the carbon footprint of Mycoprotein since 2012. In 2017 Carbon Trust recertified Marlow Foods, identifying them as being committed to reducing the carbon footprint of their products. Latest environmental impact data for two Quorn™ Mycoprotein products compared with beef and chicken are shown in Table 9. It can be seen that Quorn™ products have a significantly lower carbon footprint and levels of water usage than comparable animal products. Owing to its vertical production methods proportions of land required are also considerably lower. **The updated and overarching carbon footprint for Mycoprotein as of 2019 is expected to be 0.8 kg (CO2/kg).**

Table 9: Environmental impacts of Quorn Mycoprotein compared with Beef and Chicken

	GWP kg (CO2/kg)	Water (litres/kg)	Land (hectares/kg)
Quorn Mince	1.8	1960	0.0004
Quorn Pieces	1.7	1710	0.0003
Beef (Mince Raw)	26.7	19750	0.0035
Chicken	5.93	3970	0.0007

SECTION 11

Future directions

Overall, expanding, and increasingly affluent global populations are projected to consume more animal protein, creating huge environmental challenges with impacts on climate change, land and water use and biodiversity.

Equally, our knowledge and understanding of protein from a health stance has increased exponentially since FBDG and intakes guidelines were compiled (in the UK now three decades ago). Recognition of the growing evidence base now needs to be embedded in future protein guidelines with the following becoming increasingly apparent:

- **Protein requirements could be *higher* than anticipated** – There is a growing body of evidence for replacing nitrogen balance methods, which suggests that protein requirements could be 40% higher than current recommendations.[12] This increasingly seems to be the case for younger and older adults.

- **Guidelines need to change and include a greater diversity of proteins** – in particular plant proteins, which are more sustainable than animal proteins in terms of GHGEs, land use and water use.

- **Simple substitutes are a good way forward** – Dietary change is difficult to achieve and choices that can be directly substituted for meat in common dishes, such as Mycoprotein, soya, pulses, nuts and seeds, would appear to provide the most viable options for increasing protein diversity in the short to medium term. Use of Mycoprotein in particular has been researched over many years with several product options available to incorporate into meals in appealing ways. Education of the public, including in schools, needs to continue.

- **Protein 'distribution' is important** – Accruing science indicates that 'when' we eat protein i.e. timing and distribution throughout the day could have implications for health, in particular, muscle synthesis.

- **Protein quality to be redefined** – Latest definitions of protein quality should include more than a simple judgement made on a foods amino acid profile. Updated approaches should include quality of health and environmental outcomes associated with specific food sources of protein.

- **Other novel sources of protein will emerge** – Novel sources of protein, such as algae, insects and lab-grown meat, will have a longer adoption curve and could prove to be an important dietary element in a more protein diverse diet for a sustainable future. However, ongoing research is needed as these are largely in the earlier phases of development and industrial application.

- **Uniform definitions of 'plant-based' are needed** – Presently there is a lack of consensus. Many valuable sustainable protein sources are being overlooked and other ad hoc food groups included within such definitions.

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