

The public health rationale for promoting plant protein as an important part of a sustainable and healthy diet

M. Lonnie*  and A. M. Johnstone† 

*Department of Human Nutrition, Faculty of Food Science, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland;

†The Rowett Institute, School of Medicine, Medical Sciences and Nutrition, University of Aberdeen, Aberdeen, UK

Abstract

Sustainable diets are proposed as a means to improve public health and food security and to reduce the impact of the food system on the environment. Guidance around sustainable diets includes a reduction of animal products in order to move towards a more plant-based diet, meaning that plant-originated foods are a predominant, but not the sole component of a diet. The main principles of a sustainable diet (as provided by the Food and Agriculture Organization of the United Nations/World Health Organization) are to consume a variety of unprocessed or minimally processed foods, mainly as wholegrains, pulses, fruits and vegetables, with moderate amounts of eggs, dairy, poultry and fish and modest amounts of ruminant meat, which are consistent with the current UK healthy eating recommendations (*e.g.* Eatwell Guide). The aim of this review was twofold: (i) to discuss public health challenges associated with consumers' knowledge regarding protein sustainability, healthier protein sources and protein requirements, and (ii) to review potential approaches to facilitate the shift towards a more sustainable diet. Consumers would benefit from receiving clear guidance around how much protein is needed to meet their daily requirements. The public health message directed to a consumer could highlight that desired health outcomes, such as muscle protein synthesis and weight control, can be achieved with both sources of protein (*i.e.* animal and plant-based), and that what is more important is the nature of the 'protein package'. Health promotion and education around the benefits of plant-based protein could be one of the strategies encouraging the wider population to consider a shift towards a predominantly plant-based diet.

Keywords: animal protein, dietary protein, plant-based diet, protein requirements, sustainability, vegetarian

Introduction

It is projected that between 2010 and 2050, the world demand for food will double alongside the growing

population (from 7 billion to a projected 9.8 billion) and, consequently, the demand for animal-based foods will increase by nearly 70%, particularly from ruminant meat (from cattle, sheep and goats) (World Bank 2008; WRI 2018). Closing this food gap will intensify the pressure on land (crop and pasture yields) and contribute to an increase in greenhouse gas (GHG) emissions (Henchion *et al.* 2017). It has been estimated that to meet the growing demand, an additional

Correspondence: Prof Alexandra M. Johnstone, Personal Chair in Nutrition, The Rowett Institute, School of Medicine, Medical Sciences and Nutrition, University of Aberdeen, Ashgrove Road West, Aberdeen, AB25 2ZD, UK.

E-mail: Alex.Johnstone@abdn.ac.uk

600 million hectares of agricultural land will be required, with the annual GHG (CO₂ equivalent) emissions reaching 11.25 gigatons (Gt) in 2050 (WRI 2018). This is a significant environmental challenge because, to sustain global warming below a 1.5°C increase, the annual GHG emissions from agricultural production should not exceed a target of 4 Gt a year (WRI 2018). At a global level, ruminant livestock generate roughly half of all agricultural production emissions, of which the largest source of GHG is from 'enteric methane', which is produced by the microbes in ruminant stomachs (Audsley *et al.* 2009; WRI 2018). However, it should be noted that agricultural production GHG emission levels at a country level are dependent on the production systems adopted locally and are influenced by factors such as genetics and feed.

Due to environmental concerns, transitioning towards more sustainable diets and exploring alternative protein sources have been at the forefront of 21st century research (FAO 2010; Nadathur *et al.* 2017). Sustainable diets are defined as 'dietary patterns that promote all dimensions of individuals' health and well-being; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable' (FAO & WHO 2019). The main principles of a sustainable diet are to consume a variety of unprocessed or minimally processed foods, mainly wholegrains, pulses, fruits and vegetables, moderate amounts of eggs, dairy, poultry and fish and modest amounts of ruminant meat (FAO & WHO 2019). Despite controversies relating to environmental impact, the intake of ruminant meat is not entirely discouraged, but moderation is recommended. The principles of a sustainable diet are consistent with those of the UK's healthy eating model, the Eatwell Guide (PHE 2016), and the term is often used interchangeably with 'plant-based diet' or 'flexitarian diet', which will be discussed in more detail later. For the purpose of this review, we have used the term 'plant-based diet' throughout the paper, to mean that plants are the predominant, but not the sole, component of the diet. It needs to be stressed that this term is not synonymous with vegetarian (avoids consumption of meat, including fish) or vegan diets (additionally avoids consumption of eggs, dairy and other products derived from animals) which share a common principle of excluding meat from the diet entirely.

Despite the controversies regarding the affordability and effectiveness of the new 'planetary diet' (Hirvonen *et al.* 2019), the recent approach presented in the EAT-Lancet report (Willett *et al.* 2019) has received

much attention as a blueprint for feeding 10 billion people by 2050 while retaining planetary health. The authors considered climate change, land system change, freshwater use, nitrogen cycling, phosphorus cycling and biodiversity loss as key international targets. To achieve negative emissions globally, as described in the Paris Agreement (UNFCCC 2016), the global food system needs to become a net carbon sink from 2040 onwards. The report suggested that required changes include at least doubling the consumption of healthier foods such as fruits, vegetables, legumes and nuts, and a greater than 50% reduction in global consumption of foods such as added sugars and red meat (Willett *et al.* 2019). More precisely, the EAT-Lancet recommendations around intakes of protein foods are to reduce red meat, poultry and eggs intake to 392 g of cooked weight per week and dairy products to 250 g (0–500 g) per day (Willett *et al.* 2019). The results from other modelling studies are fairly consistent with the EAT-Lancet findings regarding the recommended reduction of meat intake, but interestingly, the recommendations regarding changes in the consumption of plant protein sources vary between the models (Scarborough *et al.* 2016; WWF 2017; Reynolds *et al.* 2019; Steenson & Buttriss 2020). For instance, the EAT-Lancet authors suggested 50 g of beans, lentils and peas and 25 g of soy beans a day, while other models calculated the percentage increase in intake: 86% increase of beans, pulses and other legumes intake (from the current 14 g to the optimal intake of 26 g/day) (Scarborough *et al.* 2016), 250% increase of legumes, nuts and oilseeds (from 11 g to 28 g/day) (WWF 2017) or no increase at all (30 g vs. 30 g/day) (Reynolds *et al.* 2019). These discrepancies are, however, not surprising and stem from the heterogeneous methodological approaches used (Steenson & Buttriss 2020).

Importantly, the planetary diet approach should be perceived as a reference diet set at a global level, recommending changes focused on environmental targets rather than on the nutritional requirements of particular population groups. Dietary approaches need to be not only environmentally sustainable but also healthy, economically fair and culturally acceptable (FAO 2012). Food waste is also an important consideration to reduce food loss during production and by consumers (HLPE 2014). Addressing this challenge involves a range of actions including improving post-harvest infrastructure, food transport, processing and packing, increasing collaboration along the supply chain, training and equipping producers, and educating consumers in order to meet the United Nations

Sustainable Development Goals (HLPE 2014; FAO 2015; Willett *et al.* 2019).

It has been well established that for environmental reasons, global dietary change is necessary. However, the nutritional implications of such a transition have recently sparked a polarised public health debate (Zagmutt *et al.* 2020; Blackstone & Conrad 2020). In response to the EAT-Lancet report, Zagmutt *et al.* (2020) replicated calculations and found that a dietary change based on merely balancing energy intake would have a very similar effect on mortality rate reduction. Furthermore, public health strategies to facilitate the necessary transition are still a fledgling topic with little evidence of what approaches might be most effective. The aim of this review is twofold: 1) to discuss public health challenges associated with protein sustainability, healthier protein sources and protein requirements and 2) to review potential avenues for formulating messages which could help to facilitate the shift towards a more sustainable diet.

Part I: Public health challenges associated with sustainable protein sources and requirements

Sustainability and ethical considerations for eating a more plant-based diet

A global change in our food system requires a combination of substantial shifts towards mostly plant-based dietary patterns and major improvements in food production practices, while recognising the need for trade-offs and at the same time avoiding unintended consequences associated with the current, and often substantial, gaps in our understanding of the sustainability credentials of alternative protein sources (Love-day 2020). The environmental footprint of food production varies depending on the food source and factors related to how and where it is being produced. Overall, production of animal-based foods has a several-fold higher environmental impact in comparison with plant-based foods (Marlow *et al.* 2009; Aleksandrowicz *et al.* 2016; Committee on Climate Change 2020). Poore and Nemecek (2018) conducted an extensive review providing a consolidated data set which covers 38 700 farms in 119 countries and 40 products (representing 90% of global protein and calorie consumption), 1600 processors, packaging types and retailers. The report covered five important environmental impact indicators: land use, freshwater withdrawals weighted by local water scarcity, GHG emissions and acidifying and eutrophying emissions

(*i.e.* sulphur dioxide, nitrogen dioxide and ammonia emissions contributing to the reduction of soil and water pH levels). The results revealed that meat, aquaculture, eggs and dairy use ~ 83% of the world's farmland and contribute 56–58% of emissions generated as a result of food production, despite providing only 37% of protein supply (Poore & Nemecek 2018). A similar illustration was brought by Sabaté *et al.* (2015) who estimated that producing 1 kg of protein from beef requires approximately 18 times more land, 10 times more water and 9 times more fuel, in comparison to 1 kg of protein from kidney bean production. Although this was a desk-based study highlighting the magnitude of the differences in animal versus plant protein production, the evidence seems to be consistent in finding that the resource use of the lowest-impact animal products typically exceeds that of plant alternatives (Marlow *et al.* 2009; Sabaté *et al.* 2015; Poore & Nemecek 2018).

On the other hand, the environmental footprint varies not only due to the protein source, but also to production practices, and this applies to both plant and animal protein sources. For example, the impact of plant food production depends on multiple factors, such as growing region, farming practices, processing and transportation (Boye & Arcand 2013). For instance, unsustainably sourced cocoa beans can generate a higher carbon footprint than a serving of low-impact beef (Poore & Nemecek 2018). Similarly, the production of food from animals is multifactorial and evidence indicates that improving animal nutrition, reproductive management, genetic merit (breeding value) or rotational grazing can result in substantial improvements in the environmental impact of meat production (White *et al.* 2015; Wang *et al.* 2020). Lastly, when comparisons are made between plant and animal proteins, beef is often used as the comparator, presumably because beef tends to have the highest footprint of all animal foods (Poore & Nemecek 2018; Kim *et al.* 2019). Other animal-based food groups can also provide dietary protein that generates a lower carbon footprint than beef, for example farmed seafood, cheese, milk, lamb, eggs, poultry and pork (Nijdam *et al.* 2012; Kim *et al.* 2019). Which foods should be avoided or reduced due to environmental reasons, and which ones should be consumed more often, raises controversy. Interestingly, modelling work has demonstrated that a plant-based diet which includes one animal-based meal per day (described by authors as '2/3 vegan') was less GHG-intensive than a vegetarian diet including dairy and eggs, which was explained by the GHG-intensity of dairy foods due to

the environmental impact of ruminants (Kim *et al.* 2019).

Different trends are encouraging the shift from meat-based to plant-based diets (FAO 2016; PHE 2016; WWF 2017). It can be observed that some consumers have started to choose diets based on locally produced foods to support the environment and reduce their carbon footprint (Nadathur *et al.* 2017). However, environmental and animal welfare aspects are not the strongest determinants of reducing animal product consumption in a general population, although the importance of these factors tends to be country-specific. In a Dutch population, health was cited as the main reason for following a vegetarian and flexitarian diet, while animal welfare was most important to vegans (De Gavelle *et al.* 2019). Similarly, in Britain, over half of the respondents (58%) of a survey of 2878 people declared that health reasons were the main drive for reducing meat intake, followed by saving money, concerns over animal welfare and food safety (NatCen 2016; Derbyshire 2017). Environmental concerns were mentioned last, by only 11% of those surveyed (NatCen 2016). Therefore, at the current stage, highlighting the environmental and animal welfare aspects as a leading motivation for a plant-based shift may not be the most effective public health strategy. Instead, stressing the benefits in terms of health gains might be more relevant to a larger group of consumers.

Health considerations for eating a more plant-based diet

Consumers are becoming increasingly aware of the health benefits of predominantly plant-based diets, which have been associated with lowering the risk of type 2 diabetes, cardiovascular diseases, hypertension, obesity, metabolic syndrome and all-cause mortality in prospective cohort studies (Yokoyama *et al.* 2014; Satija *et al.* 2016; Satija *et al.* 2017; Dinu *et al.* 2017; Kim *et al.* 2019). Analysis of dietary patterns allows for the quantitative assessment of the synergistic effects of dietary components on disease risk, including the effects of food and macronutrient substitutions (*i.e.* animal protein sources for plant sources) (Qian *et al.* 2019). In a large prospective cohort study, Song *et al.* (2016) found that replacing 3% of daily energy from animal protein with plant-based protein was associated with lower all-cause mortality. The greatest risk reductions were observed when processed red meat, unprocessed red meat and eggs were replaced with plant-based protein (HR 0.66, 0.88 and 0.81,

respectively) (Song *et al.* 2016). A more recent systematic review and meta-analysis (Qian *et al.* 2019) of prospective observational studies reported that greater adherence to a plant-based dietary pattern was inversely associated with the risk of type 2 diabetes. This is broadly in line with another meta-analysis of observational studies that suggested a vegetarian diet is beneficial for the prevention of type 2 diabetes (Lee & Park 2017). The authors identified several potential mechanisms for this effect, as plant-based diets typically emphasise fruits, vegetables, nuts, legumes and whole grains, which contain fibre, vitamins and minerals, antioxidants, phenolic compounds and unsaturated fatty acids (Hu 2003; Richter *et al.* 2015; Lee & Park 2017). Clinical trials and observational studies have suggested that these foods individually and jointly improve insulin sensitivity and blood pressure, reduce long-term weight gain and ameliorate systemic inflammation, different pathways all involved in the development of type 2 diabetes (Qian *et al.* 2019).

In addition, plant-based diets de-emphasise or reduce red and processed meat consumption. The World Cancer Research Fund and American Institute for Cancer Research (2018) recommend limiting consumption of red meat and avoiding processed meats to reduce cancer risk; specifically, to eat no more than 350–500 g (cooked weight) per week of red meats, such as beef, pork and lamb, and to avoid processed meats such as ham, bacon, salami, hot dogs and some sausages (WCRF/AICR 2018). The potential carcinogenic mechanisms linked to red and processed meat are associated with the high content of haem iron (potentially promoting colorectal tumorigenesis), carcinogenic polycyclic aromatic hydrocarbons (formed during heat processing) and exogenously derived N-nitroso compounds (in processed meats) (Santarelli *et al.* 2008). Data exploring the effects of high red meat consumption on cardiovascular health, cancer and all-cause mortality appear to be consistent (Larsson 2014; Abete *et al.* 2014; Yang *et al.* 2016; Wang *et al.* 2016; Cui *et al.* 2019; Zheng *et al.* 2019; Zhong *et al.* 2020); however, some recent reports have questioned the certainty of the evidence, particularly in terms of unprocessed red meat (Zeraatkar *et al.* 2019; Han *et al.* 2019; Vernooij *et al.* 2019; Johnston *et al.* 2019; Larsson 2014; Kim *et al.* 2019).

Updating national dietary guidelines to reflect recent evidence on healthy eating might be a solution to both improve health and reduce environmental impacts even without explicit sustainability criteria (Springmann *et al.* 2018). Guidelines, such as the UK Eatwell Guide, have been developed, which promote a mixed

and more sustainable dietary pattern, with increased intake of plant foods and reduced intake of meat (PHE 2016; Cobiac *et al.* 2016). The Eatwell Guide states that ‘some’ protein-rich foods should be eaten, visually depicting meat, fish, eggs, pulses and unsalted nuts in this section within the main image and the text also refers to ‘other proteins’ (including tofu, bean curd and mycoprotein) and provides the more specific advice ‘Eat more beans and pulses, 2 portions of sustainably sourced fish per week, one of which is oily. Eat less red and processed meat’. Advice to prepare and cook meat using methods which reduce saturated fat is also included. The Carbon Trust was commissioned by Public Health England (PHE) to analyse the environmental impacts of the new Eatwell Guide, considering GHG emissions, water consumption and land requirements and concluded that adhering to this guidance would lead to an appreciably lower environmental impact than current UK diet patterns (Carbon Trust 2016). The principles of such an approach are in line with a newly emerged trend of ‘flexitarianism’. The term is a portmanteau of ‘flexible’ and ‘vegetarian’, referring to an individual who follows a primarily but not strictly vegetarian diet, occasionally eating meat or fish, allowing flexibility to choose when to eat meat or not, for example on ‘meat-free Monday’ choosing plant-based meals (Oxford English Dictionary 2014; Derbyshire 2017; Spencer & Guinard 2018). This trend reflects those consumers who are meat reducers – in line with a more environmentally sustainable eating approach. It has been estimated that, in Britain, around 14% of adults identify themselves as flexitarians, with the vast majority declaring themselves to be meat-eaters (73%) (YouGov 2019).

A rapid transformation to a predominately plant-based diet is unlikely to be feasible on the global scale, with meat consumption still being relatively high (OECD/FAO 2017). The global trend in consumption is increasing, with the highest supply of meat (excluding seafood and fish) being observed in the US, Australia, Argentina, New Zealand and Spain (124 kg, 122 kg, 109 kg, 101 kg and 100 kg per capita/annually, respectively) (FAO 2020). It is predicted that global meat consumption per person will plateau by 2026, but due to population growth and increasing prosperity in low- and middle-income countries, total meat consumption is expected to continue increasing by approximately 1.5% annually (OECD/FAO 2017). In Britain, annual per capita meat consumption (excluding fish and seafood) in 2017 was twice the world average at 82 kg/person/year, with the highest contribution being from poultry (32 kg), followed by pork

(25 kg), bovine meat (18 kg), mutton and goat (4 kg), offal (2 kg) and other meats (1 kg) (FAO 2020). It needs to be clarified that these data have not been corrected for waste at the household level so may not directly reflect the quantity of food consumed by a given individual. Nevertheless, although the average intake of red and processed meat in Britain (62 g/person/day) (Roberts *et al.* 2018) is below the recommendation to consume no more than 70 g per day (or 500 g per week) cooked weight (PHE 2016) about a third of adults aged 19–64 years are consuming more than the 90 g per day level, above which people are advised to reduce their consumption.

Do plant-based diets provide sufficient protein?

Along with the popularity of high-protein diets, such as Dukan or Paleo, protein has become a hot topic in the media, food sector and academic settings. Protein is currently one of the most sought after nutrients but it is also the one which raises the most controversies and confusion among consumers (IFIC Foundation 2018). In general, consumers are able to describe the functions of protein in the diet. The most commonly reported physiological functions of protein among consumers refer correctly to protein being a muscle building material, contributing to muscle health, and a weight-loss tool, due to its appetite-suppressing properties (Banovic *et al.* 2018).

It appears that the gap in consumers’ knowledge lies in recognising good dietary sources and estimating quantities that are sufficient for health (Tarabella & Burchi 2015; Nielsen 2018). This could be due to the lack of clear guidance available to the consumer [*i.e.* UK advice to eat ‘some’ protein foods, in contrast to the more prescriptive 5 A DAY message for fruit and vegetables (Stevenson *et al.* 2018)]. Furthermore, the recent overwhelming marketing of high-protein products may give the consumer an impression that he needs to consume more protein than he already does.

Protein requirements can be expressed in two ways: (i) as an Acceptable Macronutrient Distribution Range (AMDR), which is expressed as a recommended percentage of total energy (caloric) intake (USDA & HHS 2015a), or (ii) as a Reference Nutrient Intake (RNI), referring to the amount of protein required per kg of bodyweight (COMA 1991). The AMDR suggests that protein should contribute between 10–35% of daily calories (adults) (USDA & HHS 2015b). In the UK, on average, protein intake for men and women provides the body with approximately 17% of its dietary energy (Roberts *et al.* 2018). The UK RNI

is set at 0.75 g per kg of bodyweight (bw)/day, which equates to approximately 56 g/day and 45 g/day for men and women, respectively (aged 19 years and over) based on average bodyweights at the time (COMA 1991). However, these calculations refer to an average man (75 kg) and woman (60 kg) three decades ago, when COMA guidelines were published. Average weights of men and women in the UK have increased since then and in England are now 85 kg and 72 kg, respectively (HSE 2019), and so protein requirements are now higher than they were in 1991. Nevertheless, current average intakes of 87 g/day in men aged 19–64 years and 67 g/day in women aged 19–64 years are still likely to be sufficient for most individuals (Roberts *et al.* 2018).

The adequacy of the RNI for older adults, however, has been questioned as it does not take into account the increased protein needs of older individuals (Phillips *et al.* 2016; Lonnie *et al.* 2018). It has been well established that the amount of protein required changes across the life course (Bauer *et al.* 2013; Deutz *et al.* 2014; Phillips *et al.* 2016). A gradual decline in muscle mass and strength is observed from the third decade of life (a process known as sarcopenia) (Lexell *et al.* 1988) and an ageing adult undergoes physiological changes which affect protein utilisation and subsequent requirements (*e.g.* anabolic resistance, insulin resistance, impaired digestion, inflammation and decreased IGF-1 levels) (Wolfe *et al.* 2008; Bauer *et al.* 2013; Deutz *et al.* 2014). Therefore, the protein requirements of an ageing adult should address these increasing physiological needs (Lonnie *et al.* 2018). In the British population of older adults, the risk of inadequate protein intake might be an issue (Stevenson *et al.* 2018; Lonnie *et al.* 2018; Morris *et al.* 2020). The PROT-AGE Study Group suggested that protein intake should be increased to 1.20 g protein/kg bw, for healthy adults aged over 65 years, and to 1.50 g protein/kg bw for those with acute or chronic diseases (Bauer *et al.* 2013), figures that are in line with recommendations from the European Society for Clinical Nutrition and Metabolism (ESPEN) (Deutz *et al.* 2014). Currently, the daily intake of protein in the UK in adults aged 65 years and over is 76 g for men and 60 g for women (Roberts *et al.* 2018). Considering the increased requirement due to age and high body mass index (BMI) (28 kg/m² in adults > 65 years old) (HSE 2019), there is a strong possibility that the protein needs of at least some of this population group are not being met.

Nevertheless, despite these concerns, the required daily amount of protein is achievable regardless of the

diet type (Segovia-Siapco & Sabaté 2019). In general, most plant-based foods contain less protein per 100 g weight (or serving) than animal sources (PHE 2015). For instance, 100 g of chicken, beef or reduced-fat Cheddar cheese provides around 30 g of protein per 100 g, while most pulses and cereals contain < 20 g and < 15 g per 100 g, respectively, although some pulses can have up to 40 g of protein per 100 g (like soya or lupin) (PHE 2015). The bioavailability of plant versus animal protein will be discussed further, later in the paper (see protein quality). A study in a Swiss cohort of adults (aged 18–50 years) observed that although protein intake was significantly higher in the omnivore group (85 ± 24 g/day), the intake observed among vegetarians and vegans was still sufficient (64 ± 21 and 65 ± 21 g/day, respectively) (Schüpbach *et al.* 2017). Therefore, when formulating public health messages, consumers could benefit from being reassured that following a healthy, balanced diet (plant-based or not) will most likely cover their protein requirements. At the same time, if there is no contraindication (*e.g.* kidney diseases), overweight and older individuals may need to increase their intakes of protein-rich foods to slow the decline in muscle loss and prevent sarcopenia (Morris *et al.* 2020).

Do plant-based diets provide protein of adequate quality?

One of the common concerns among consumers is recognising which foods are good protein sources and whether proteins from plants are of as good quality as those from animal-derived foods (IFIC Foundation 2018). Protein quality is determined by assessing its essential amino acid composition, and the bioavailability and digestibility of its constituent amino acids.

The main role of dietary protein is the contribution to physiological body protein synthesis (including muscle protein synthesis), bone maintenance, ensuring the normal growth and development of children and adolescents, and supporting recovery of individuals in catabolic states (*e.g.* people with severe illness or injury, elderly) (FAO 2013). This process can be optimised with the ingestion of ‘complete proteins’, which are mostly found in animal-based foods (FAO 2013). The essential (or indispensable) amino acids (EAA) are the nine amino acids that cannot be synthesised by the body but must be provided in the diet. The term ‘complete protein’ indicates that all the EAA in a given food are in sufficient quantities and in the right proportion for human nutrition requirements (FAO 2013).

Proteins found in plants are often described as incomplete. This is because some of the EAA in plant-based foods are in lower quantities than in the reference amino acid pattern (Millward *et al.* 2008; FAO 2013). The reference pattern provides guidance regarding the quantities of each EAA in an optimal dietary protein source, expressed as mg EAA per 1 g of protein (FAO 2013). In comparison with animal proteins, those in plant-based foods contain lower amounts of lysine, methionine and leucine (van Vliet *et al.* 2015; Gorissen & Witard 2018). Therefore, in order to compose a plant-based meal with a nutritionally balanced amino acid profile, the concept of complementation was introduced (Young & Pellett 1994). Using complementary plant proteins means different plant proteins complement each other in their amino acid pattern, so that when two foods providing vegetable protein are eaten at a meal, such as baked beans on toast, comprising a cereal-based food (*e.g.* bread) and pulses (*e.g.* baked beans), the amino acids of one protein source may compensate for the limitations of the other, resulting in a combination with a higher amino acid score of the meal (ratio of EAA in food to the reference value in the pattern) (FAO 2013). Therefore, a plant-based diet can achieve the optimal quality of protein without animal-based proteins. In fact, complementary proteins do not have to be consumed at the same time, and the benefits of the complementation can be achieved by increasing the quantity and variety of plant-based foods consumed over the course of a day (Young & Pellett 1994; American Dietetic Association 2009). Furthermore, a recent study found that supplementing plant foods with probiotics can increase postprandial serum concentration of EAA, compensating nutritional limitations of plant protein sources (Jäger *et al.* 2020). However, for consumers to successfully adopt this approach, they would need to be aware of the importance of combining sufficient amounts of different complementary plant sources of proteins such as pulses and cereals.

The next step in assessing protein quality is measuring its bioavailability and digestibility. For plants, this will be heavily influenced by factors such as nutrients available during growth (*e.g.* soil conditions) and processing. The bioavailability of protein from plant-based foods is lower than from animal foods, due to anti-nutritional factors (Gilani *et al.* 2005; Multari *et al.* 2016). Anti-nutrients are naturally occurring compounds found in plants (*e.g.* saponins, tannins, phytates or lectins), which serve as a 'self-defence' mechanism against fungi, bacteria or pests (Rousseau

et al. 2020). From the human nutrition perspective, anti-nutrients can impair the digestion and absorption of protein and other nutrients, such as iron, which is a commonly reported concern of the consumers (Corrin & Papadopoulos 2017; Rousseau *et al.* 2020). Hence, to obtain the required protein intake from plant-based sources, some level of food preparation knowledge might be required to optimise protein bioavailability. For example, soaking, cooking, roasting or fermenting have been shown to be effective strategies to partially remove anti-nutritional factors from plant-based foods such as pulses and increase the bioavailability of desirable compounds (Sharma & Sehgal 1992; Jamalian & Ghorbani 2005; Osman *et al.* 2014; Rousseau *et al.* 2020).

There are several approaches for assessing overall protein quality. The method that has been most commonly used in the past few decades and takes into account both the EAA profile and protein digestibility is the digestibility-corrected amino acid score (PDCAAS) (FAO 2013). More recently, the FAO has recommended a revised score of AA evaluation, called the digestible indispensable amino acid score (DIAAS). To calculate DIAAS, it is necessary to determine the digestibility of each individual AA at the end of the small intestine (the ileum) (FAO 2013). It is anticipated that, in the future, there will be more research on this approach to compare and contrast the quality of plant proteins to that of animal protein sources (Marinangeli & House 2017).

In addition to assessing the quality of protein as an isolated nutrient, a wider perspective is needed, since people eat food and tend not to consume protein in an isolated form (with the exceptions of protein supplements). It might be beneficial to perceive foods as protein carriers and evaluate the risks and benefits of food groups using a more holistic approach. The term 'protein package', proposed by the researchers from the Harvard School of Public Health (Guasch-Ferré *et al.* 2019), may be more easily understood by the consumer. Animal proteins come with a 'package' of essential nutrients, some of which are not found in plant-based foods [*e.g.* vitamin B12, choline, carnosine, L-carnitine, creatine, CoQ10, CLA and certain long-chain omega-3 fatty acids (DHA, EPA)] (Olmédilla-Alonso *et al.* 2013). Also, micronutrients such as zinc and iron are often found in higher quantities in animal-based foods and are more bioavailable in comparison with iron and zinc from plant-based foods (Lim *et al.* 2013). On the other hand, the animal 'protein package' is also often a source of saturated fatty acids and/or carcinogenic heterocyclic amines (formed

after cooking at high temperatures) (Santarelli *et al.* 2008; O'Sullivan *et al.* 2013). Within the plant 'protein package' the consumer receives components absent or limited in animal foods [*e.g.* dietary fibre (pectins, inulin, lignans, resistant starch, β -glucans), polyphenols (*e.g.* flavonoids) and higher amounts of vitamin C and polyunsaturated fatty acids (excepting oil-rich fish)] (Hu 2003; Richter *et al.* 2015).

In conclusion, although animal-based proteins are superior to plant-based protein in terms of their EAA profile and their bioavailability, a plant-based diet with sufficient protein intake is achievable. This can be facilitated by consuming larger quantities of a variety of protein-containing plant-based foods, which will ensure that diets are composed of complementary dietary sources, optimising the amino acid profile. The inclusion of more plant-based foods could provide the desired protein benefits with fewer associated health risks compared with the excessive intake of animal foods. The public health message directed to the consumer could highlight that the desired health outcomes, such as muscle protein synthesis and weight control, can be achieved with both types of protein sources and that what is more important is the nature of the 'protein package'.

Part II: Potential avenues for formulating messages

What sort of public health messages should be adopted to encourage the shift towards more plant-based protein diets?

There is now a growing literature on translating policy action for a healthy and sustainable diet for consumers (Watts *et al.* 2015). For example, in Denmark there is the 'Nordic Diet', inspired by the Mediterranean diet, which has been developed as a palatable, healthy and sustainable diet based on products from the Nordic region (Jensen & Poulsen 2013). Also, in the US, the recent focus on healthy eating patterns within US dietary guidelines includes advice on both the Mediterranean-style eating pattern and a vegetarian eating pattern (USDA & HHS 2015a, 2015b), highlighting plant protein sources.

In the UK, the Food Foundation (<https://foodfoundation.org.uk>) is an active independent organisation working in partnership with researchers, campaigners, community bodies, industry, government and citizens to support the shift towards a sustainable food system which delivers health and wellbeing for all. Their recent initiative 'Peas Please' was set up in 2016 with

a mission 'To make it easier for everyone in the UK to eat more vegetables' (The Food Foundation 2019). The support from major retailers, caterers and government has facilitated their aim to drive food system change and increase vegetable consumption.

However, population-level sustainable dietary advice or interventions may not produce the same effects in high- and lower-income groups (Reynolds *et al.* 2019). The need for tailoring changes to income groups to minimise health inequalities and make dietary changes more achievable has been highlighted. Tailored dietary advice or interventions that keep dietary change to a minimum may be more effective to shift income groups to healthy and sustainable diets. Since cost is often perceived as a barrier to the uptake of healthy, lower GHG emission diets (Dixon & Isaacs 2013), the *Living Cost and Food Survey* has been used to model dietary changes required to shift the UK population to diets that meet dietary recommendations for health, have lower GHG emissions and are affordable for different income groups. In the optimised diets, the food sources of GHG emissions differed by income group due to their cost and the intention to keep the level of necessary change from current diets to a minimum. Broadly, the changes needed were similar across all groups (*i.e.* reducing animal-based products and increasing plant-based foods), but varied by specific foods. It was reported that it was possible to create diets with a 57% reduction in GHG emissions that met dietary and cost restraints in all income groups (Reynolds *et al.* 2019).

However, studies have shown that reducing dietary cost can result in rebound effects (Sorrell & Dimitropoulos 2008; Grabs 2015), where money saved in one part of the household budget (*e.g.* food or energy use) is spent on more GHG emission-intensive items elsewhere (*e.g.* travel, entertainment), particularly for lower-income consumers. To reduce rebound effects, dietary change must be accompanied by broader transitions in consumption to a healthier, lower GHG emissions lifestyle. One of our own research group's recent qualitative research papers (McBey, Watts & Johnstone 2019) has considered more direct measures that go beyond simply informing the public. This paper considers three possible avenues through which more sustainable meat consumption patterns may be promoted: 'nudging', the formulation of new meat-alternative products and targeting those in particular stages of the life course. Through focus groups held in various locations in Scotland, the perceived viability of these measures was explored. While each measure showed some promise for reducing Scottish meat

intake, the complex nature of food choice means that more qualitative research into meat consumption in Scotland is required. This work also highlights that there is no 'one size fits all' approach for supporting a shift in meat consumption. The challenges for food transition in the UK are not distinct. For example, a recent qualitative study on European consumers which reported food preferences in older and mixed-age participants, based on their perception of foods high in protein (Banovic *et al.* 2018), highlights the fact that participants could not differentiate between foods naturally high in protein and foods with enhanced (increased) protein content (*i.e.* foods with protein as an added ingredient), no matter whether foods originated from animal or plant source. Furthermore, older-aged participants expressed more scepticism towards foods with increased protein content than mixed-age (19–68 years-old) participants (Banovic *et al.* 2018). The reported main obstacles for plant protein and specifically legume protein preference were, lack of trust in products, perceived unethical production, bad sensory qualities in terms of product taste, as well as perceived lack of healthiness.

Understanding the differences between omnivores, vegetarians and vegans in terms of socio-demographic and attitudinal background may be useful to support dietary change towards a more plant-based protein diet. A US cohort study analysed predictors of plant protein consumption (Aggarwal & Drewnowski 2019), reporting that being a woman, non-White, with higher education level and considering healthy eating as an important factor were all associated with higher plant protein consumption (Aggarwal & Drewnowski 2019). Interestingly, income was not correlated with plant protein consumption in this cohort.

Positive attitudes towards healthy eating appear to be a common theme among vegetarian consumers reported in other studies (*e.g.* Alles *et al.* 2017; Povey *et al.* 2001; De Gavelle *et al.* 2019). Povey *et al.* (2001) observed that individuals were more likely to consider making a shift towards a plant-based diet if they had a strong identity as a healthy eater. Similar findings have been reported in a representative sample of French adults (De Gavelle *et al.* 2019). In comparison with omnivores, vegetarians were more likely to be female, within a healthy BMI range and single (De Gavelle *et al.* 2019). In this study, attitudes were the strongest predictors of intentions to reduce meat consumption and incorporate a plant-based diet, followed by social norms and perceived behavioural control. Consistently, price was not a predictor of a low-meat diet. Hence, promoting healthy eating attitudes in

combination with increasing consumers' nutritional knowledge might be a justified strategy to implement when designing public health initiatives.

A recent paper from Waters (2018) explores rates of vegetarianism and veganism in the UK over time and provides a detailed discussion around national data obtained at different time points. The authors reported average rates of vegetarianism and veganism in the UK of 2.9% and 0.4%, respectively, in 2014, for households where the respondent was born between 1930 and 1974. In comparison, for adults more generally, a 2014 British Social Attitudes survey reported rates of 5.9% and 0.2%; a 2016 Food Standards Agency survey reported rates of 3% and 1% (FSA 2017); a 2016 Ipsos MORI survey (Ipsos MORI 2016) reported rates of 2.2% and 1.1%, while a 2017 Mintel survey reported rates of 3.9% and 1.0%, respectively (Waters 2018).

Perhaps a twin-track approach could be considered, combining strengthening the current practice of health-conscious consumers in parallel with investigating and removing barriers to increase consumption of nutrient dense plant-based foods by those who are less health-conscious. Lower intakes of plant protein have been associated with being male, having a higher income, lower education level and not placing importance on healthy eating (Corrin & Papadopoulos 2017; De Gavelle *et al.* 2019; Aggarwal & Drewnowski 2019). Still, it needs to be stressed that cautious assessment of overall nutritional quality of foods being marketed as 'plant-based' is needed, as not all plant alternatives have a healthier nutritional profile. For example, a survey by Action on Salt (2018) found that some meat-alternatives had higher salt content than the meat products they were replacing. Therefore, health education and promotion on the benefits of plant-based protein could be one of the strategies to encourage the wider population to consider such shift.

Conclusions

In order to facilitate the shift towards the more plant-based diet depicted in national food guidelines such as the UK's Eatwell Guide (2016), it is crucial to develop successful public health strategies. These can be achieved by segmenting the public and identifying target population groups. As highlighted by McBey *et al.* (2019), there is not a one-fits-all approach to helping consumers to rebalance their diet by reducing animal-based protein intake, and at least a few avenues need to be considered. Analysing consumer behaviour and

motives behind dietary choices can help to formulate appropriate messages and determine which communication channels are most appropriate for each segment. Consumers would benefit from receiving clear guidance of how much protein is needed to meet their daily requirements. For instance, information in a mix and match format about appropriate portion sizes of different protein-containing foods that together can deliver daily protein needs. The public health message directed to a consumer could highlight the fact that desirable health outcomes, such as muscle protein synthesis and weight control, can be achieved with both animal and plant sources of protein and that what is more important is the nature of the 'protein package' (*i.e.* the other nutrients being provided by protein-rich foods). Health promotion and education of the benefits of plant-based protein could be one of the strategies to encourage the wider population to consider a shift towards a more plant-based diet.

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