Meeting report: plant-rich dietary patterns and health

Woodside, J. V., Sun, Q., de Roos, B., Rimm, E. B., Hu, F. B., Heinen, M. M., McEvoy, C. T., Piernas, C., Scheelbeek, P. F. D., Rushton, J., Ensaff, H., Brennan, S. F., & Brennan, L. (2022). Meeting report: plant-rich dietary patterns and health. *The Proceedings of the Nutrition Society*, *81*(4), 288-305. https://doi.org/10.1017/S002966512200266X

Published in:
The Proceedings of the Nutrition Society

Document Version:
Publisher's PDF, also known as Version of record

Proceedings of the Nutrition Society (2022), **81**, 288–305 doi:10.1017/S002966512200266X

First published online 23 August 2022

The Nutrition Society Member-led Meeting was held online on 4–5 October 2021

Conference on 'Plant-rich dietary patterns and health'

Report of a member-led meeting: plant-rich dietary patterns and health

Jayne V. Woodside[1]*, Qi Sun[2], Baukje de Roos[3], Eric B. Rimm[2], Frank B. Hu[2], Mirjam M. Heinen[4], Claire T. McEvoy[1], Carmen Piernas[5], Pauline F. D. Scheelbeek[6], Jonathan Rushton[7], Hannah Ensaff[8], Sarah F. Brennan[1] and Lorraine Brennan[9]

[1]*Centre for Public Health, Queen's University Belfast, Belfast, UK*
[2]*Harvard TH Chan School of Public Health, Boston, USA*
[3]*The Rowett Institute, University of Aberdeen, Aberdeen, UK*
[4]*WHO European Office for Prevention and Control of Noncommunicable Diseases, Department of Country Health Programmes, WHO Regional Office for Europe, Geneva, Switzerland*
[5]*Nuffield Department of Population Health, University of Oxford, Oxford, UK*
[6]*Faculty of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, London, UK*
[7]*Institute of Infection, Veterinary and Ecological Sciences, University of Liverpool, Liverpool, UK*
[8]*School of Food Science and Nutrition, University of Leeds, Leeds, UK*
[9]*School of Agriculture and Food Science, University College Dublin, Dublin, Ireland*

Dietary patterns (DP) rich in plant foods are associated with improved health and reduced non-communicable disease risk. In October 2021, the Nutrition Society hosted a member-led conference, held online over 2 half days, exploring the latest research findings examining plant-rich DP and health. The aim of the present paper is to summarise the content of the conference and synopses of the individual speaker presentations are included. Topics included epidemiological analysis of plant-rich DP and health outcomes, the effects of dietary interventions which have increased fruit and vegetable (FV) intake on a range of health outcomes, how adherence to plant-rich DP is assessed, the use of biomarkers to assess FV intake and a consideration of how modifying behaviour towards increased FV intake could impact environmental outcomes, planetary health and food systems. In conclusion, although there are still considerable uncertainties which require further research, which were considered as part of the conference and are summarised in this review, adopting a plant-rich DP at a population level could have a considerable impact on diet and health outcomes, as well as planetary health.

Key words: Diet: health: Fruit: Vegetables: Dietary patterns: Plant-rich dietary patterns

Dietary patterns (DP) rich in plant foods are associated with improved health and reduced non-communicable disease (NCD) risk. Fruit and vegetables (FV) are a cornerstone of healthy dietary recommendations. FV include a diverse collection of plant foods that vary in their energy, nutrient and dietary bioactive contents. FV have potential health-promoting effects beyond providing basic nutrition needs in human subjects, including antioxidant and anti-inflammatory properties, yet current global intakes of FV are well below recommendations.

Abbreviations: AD, Alzheimer's disease, DP, dietary pattern, FV, fruit and vegetable, MD, Mediterranean diet, NCD, non-communicable disease, PDI, plant-based diet index, T2D, type 2 diabetes.
***Corresponding author:** Jayne V. Woodside, email j.woodside@qub.ac.uk

Given the importance of FV for health, interventions that promote FV intake are warranted.

A plant-rich DP, as compared to current average diets in the Global North, is likely to have health benefits on a range of NCD, but is also likely, if followed on a population level, to have beneficial impacts on planetary health[1]. There are different degrees of dietary restriction in terms of removing foods of animal origin and increasing intakes of foods of plant origin. Therefore plant-focused DP can range from a vegan diet which avoids all food of animal origin, through a vegetarian diet which avoids meat, to an omnivorous DP which is still rich in FV. There are some uncertainties regarding the ability of an individual to meet nutritional requirements when following the more restrictive DP (i.e. vegan and vegetarian), particularly in terms of micronutrients (e.g. vitamin B_{12}), although increasing dietary diversity can help support the maintenance of adequate nutrient intake. There can also be significant variations in diet quality even within DP that are similarly plant-rich. Finally, costs of healthier foods such as FV, particularly when expressed adjusted for energy density, have frequently been demonstrated to be higher, which means that the known socioeconomic differential in dietary quality is likely to be enhanced as increased FV intake is promoted.

In October 2021, the Nutrition Society hosted a member-led conference, held online over 2 half days, exploring the latest research findings examining plant-rich DP and health. The term plant-rich DP was used rather than plant-based DP as the full spectrum of degrees of food group restriction outlined earlier was included. The conference attracted more than 380 registered delegates. A range of invited speakers covered topics including epidemiological analysis of plant-rich DP and health outcomes, the effects of dietary interventions which have increased FV intake on a range of health outcomes, how adherence to plant-rich DP is assessed, the use of biomarkers to assess FV intake and a consideration of how modifying behaviour towards increased FV intake could impact environmental outcomes, and food systems.

Speaker summaries

Plant-based diets and cardiometabolic health

The conference opened with a presentation by Dr Qi Sun from the Harvard TH Chan School of Public Health, exploring epidemiological evidence linking plant-based diets, which will be important in terms of improving planetary health, and cardiometabolic health, but also offering mechanistic insights as to how such diets might affect health outcomes. Dr Sun suggested that any observed associations with disease outcomes have to be further explored in terms of their biological plausibility or mechanisms. Mechanistic pathways can be explored through a multi-layer systems epidemiology approach[2], including disease risk factors, e.g. blood lipids, glycaemic markers, BMI, blood pressure and omics data, including metabolomics of endogenous metabolites, metabolomics of functional exogenous compounds, microbiome, proteomics and other omics data, to examine candidate pathways or discover new pathways. The last layer integrates multi-omics with genomics and exposome data to further shed light on mechanisms and whether mechanisms differ according to sub-groups.

Despite the fact that we know plant-based diets are healthy, in the era of precision medicine, a new question arises that whether a healthy diet can really benefit everyone. Given the between-individual variability that is determined by, for example, genetics, existing conditions, culture differences, it may be unrealistic to assume that a good diet is equally beneficial to everyone. This is the basis of the framework of precision nutrition[3]. This framework emphasises collecting comprehensive dietary and lifestyle data, using multi-omics approaches to understand biological responses to these environmental factors, using big data analysis strategies to interrogate the data and lastly developing algorithms to predict who might respond well to dietary interventions and who might not.

Dr Sun then highlighted some of the latest studies related to precision nutrition research to understand the mechanism by which plant-rich DP may impact on health outcomes, and whether this impact is similar for all. Most precision nutrition studies to date have focused on macronutrients, although plant-based diets are complex, as they can take many different forms depending on the combinations of individual plant-based foods, with resulting variability in the composition of phytochemicals (e.g. flavonoids, lignans, glucosinolates, coumarins, lycopene, α- and β-carotenes). Given this complexity, while it is necessary to conduct precision nutrition studies to understand the variation in response to whole plant-based diets, it is also important to understand the metabolism of phytochemicals that can be highly variable among individuals.

In this regard, a series of studies have examined between-person variabilities in the bioavailability of compounds such as flavanones, enterolignans and isoflavones in controlled feeding studies in which participants consumed the same amount of test foods. There are many factors such as genetics, pre-existing conditions or even chewing, that can modify variation in response, but gut microbiome will also be important, and Dr Sun presented some key samples of this[4–7].

Inter-relationships between plant-based diets, gut microbiome and cardiometabolic health have been examined, for example, with Li *et al.*[8] assessing overall plant-based diet index or PDI, the healthy PDI, the unhealthy PDI and individual components in more than 300 men within the health professionals follow-up study. Investigators found very similar profiles of species that were associated with both overall PDI and healthy PDI, but the findings were quite different for the unhealthy PDI[8].

In conclusion, consuming a plant-based diet is important to the health of human beings and the planet, but Dr Sun argued that precision nutrition research is needed to understand inter-individual variabilities in responses to plant-based diets, suggesting it is important to understand the food metabolome and the determinants of between-individual variabilities. Specifically human gut microbiota may play a pivotal role in determining the health benefits of consuming plant-based diets, but more research is needed.

Inter-individual variation in response to consumption of plant food

The second speaker was Professor Baukje de Roos from The Rowett Institute at the University of Aberdeen, who similar to Dr Sun, focused on inter-individual variation in response to consumption of plant food, but who also considered implications for dietary guidelines.

Professor de Roos initially gave an overview of the current evidence for inter-individual variation in response to consumption of plant-based foods. There are a number of ways to identify inter-individual variability in dietary response and these include data stratification, systematic analyses of published data which reveal factors driving inter-individual variability in responsiveness to consumption of plant-based bioactives, with respect to clinical cardiometabolic biomarkers and finally more advanced study designs and statistical tools to identify responders and non-responders and develop prediction models of response. A number of studies were highlighted which used the data stratification approach (e.g. a critical review of clinical outcomes in response to coffee consumption[9]). Most studies using this approach do not, however, have enough statistical power to really explore stratification. Moreover, the systematic analyses of published data tend to include studies which have been conducted for another purpose and have not been specifically designed or powered to detect novel factors associated with response.

What is required are specifically designed studies or analyses to systematically determine factors associated with heterogeneity in response to a particular food or diet and Professor de Roos outlined a statistical analysis pipeline that might be used to assist with this. Work to date has indicated that no one method is consistently better than others and different models and approaches may be required for different datasets. What is also important is, as Dr Sun had also suggested, exploring mechanisms underpinning inter-individual variability and Professor de Roos discussed the microbiome, seeing as it plays an important role in the metabolic fate of plant-based bioactives and individual level responses to dietary polyphenol intake. For example, a trial exploring the effect of soya isoflavones in equol producers and non-producers found effects on carotid-femoral pulse wave velocity only in those who were equol producers[10].

Considering potential implications for dietary guidelines that aim to encourage consumers to shift to more plant-based diets, Professor de Roos used the ‘Five a Day’ and fibre dietary guidelines as examples. Although the ‘Five a Day’ message is well known, there is complexity over what is included in the message and the guideline has not been successful in changing intake, particularly in more disadvantaged communities, with little change observed in the National Diet and Nutrition Survey over the past 15 years[11]. Professor de Roos suggested that personalised and precision approaches may make adherence to current dietary guidelines easier, more attractive and more inclusive, and asked whether, if simple current guidelines have not been effective, could potentially more complicated, but more precise, dietary guidelines be more effective. The effect of personalised nutrition advice at an individual level has been demonstrated in the Food4Me study, where, following a 6 month intervention, participants randomised to personalised nutrition arms consumed less red meat, salt and saturated fat, increased folate intake and had higher healthy eating Index scores than those randomised to the control arm[12]. Food4Me specifically tested personalised dietary advice but there is also a need to understand, via the lens of precision nutrition, the responders to dietary change and factors determining response to dietary change; Professor de Roos concluded by suggesting that such approaches could be important for both primary and secondary NCD prevention.

Assessing fruit and vegetable intake: the use of biomarkers

The next presenter was Professor Lorraine Brennan from University College Dublin, who explored the use of biomarkers to assess FV intake. Professor Brennan initially highlighted the interest in dietary biomarker assessment, given the known limitations of traditional dietary assessment methods. Professor Brennan pointed out that, while objective biomarkers can be useful and deal with some of the weaknesses of traditional methods, that they will never negate the need for the use of the traditional self-reported methods such as questionnaire/diary methodologies to, for example, provide the context of how people are eating. The novelty will be in trying to use the self-reported data in combination with the new and emerging biomarkers. Professor Brennan pointed to the range of reviews carried out by the FoodBall consortium including those focused on FV and then discussed the range of ways in which these biomarkers can be used, including to measure adherence to a dietary intervention[13], to provide objective measures of dietary intake, to correct self-reported dietary intake data[14] and to explore relationships with health/disease parameters.

Professor Brennan then looked at an example of a biomarker of FV intake that could be considered an objective measure of dietary intake. In an ideal world biomarker concentration would be determined in a biological sample and allow calculation of food intake in g daily. An example where this works is for proline betaine, where acute feeding studies demonstrated increased urinary proline betaine excretion as intake increased. In comparison to a 4 d semi-weighed food diary reporting citrus intake data from the National Adult Nutrition Survey , biomarker data from controlled feeding studies were used to estimate intake based on urinary analysis using test and confirmation datasets. Predicted orange juice intake based on both 24 h and fasting urine sample proline betaine data was highly correlated with actual reported orange juice intake (r 0·86–0·92)[15].

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

Such findings have applications in epidemiology in terms of using biomarkers to correct measurement error in studies with traditional dietary assessment via the use of calibration equations[16]. This possibility was demonstrated successfully and the calculation methods are available online[17]; in terms of the question of how much biomarker data would be needed to be able to conduct such calibration, the conclusion was that biomarker data would be needed for approximately 20–30 % of the population. Although this example was for citrus intake, there are further examples, using similar approaches but applying them to different foods.

Recent work has highlighted that for many foods a biomarker panel approach will be required. Professor Brennan described a dose–response study attempting to categorise participants into categories of intake, then validating it using the cross-sectional national adult nutrition study[18]. Using the three biomarkers xylose, proline betaine and hippurate, a set of combined biomarker cut-offs were developed related to fruit intake category; applied to the National Adult Nutrition Survey data; the biomarker and self-report data were very compatible, with some levels of disagreement at the lowest and highest categories[18].

Ultimately it would be valuable to be able to use these panels of biomarkers to describe what people are eating – this requires complex statistics so the Brennan group have developed a new framework that would allow the modelling of multiple markers against continuous dietary intake data; this is called multiMarker software[19]. It gives intake prediction and also CI around that estimate; an app and R-package are also freely available[19]. Professor Brennan predicted that we will see more of these panels of biomarkers being developed and used for different foods.

The potential of combinations of objective biomarkers to predict DP and group people into these patterns based on their urinary metabolomics profile without the use of self-reported data was then discussed. Again the model was based on one dataset and then tested in a separate dataset. Four DP were identified based on urinary metabolites which were associated with nutrient status and these patterns were demonstrated to be reproducible over four timepoints[20].

Biomarkers may be influenced by other factors, including genetics and microbiome, as well as food intake. This does not preclude their use as biomarkers of food intake but this possibility of other influences does need to be acknowledged and accounted for when examining links with health parameters, disease risk factors and disease outcome measures.

Professor Brennan then concluded, stating that metabolomics can lead to the identification of food intake biomarkers, but that these biomarkers do need to be validated using robust methods. In the examples given, it was demonstrated that biomarkers can perform well for determining intake compared to 4 d food records (e.g. proline betaine) and to classify people into categories of fruit intake using a panel of biomarkers. There is great potential for combining biomarkers with food intake data but the statistical methods and models to achieve this still require further development. In terms of challenges, more work is required exploring unassigned features in metabolomics profiles and there is a need for international alignment and efforts in this area. Validation requirements have already been developed; the development of biomarkers and biomarker panels for DP shows promise but is at an early stage, as is the methodology about combining biomarker data with traditional dietary assessment methods.

Fruit and vegetable intake and cardiovascular risk factor status: conducting pooled analysis

The second session of the meeting began with Professor Jayne Woodside, of Queen's University Belfast, who based her talk on the fact that the majority of studies exploring FV intake and both CVD risk and CVD risk factors are observational in nature. Latest analyses of the nurses' health study (1984–2014) and health professionals follow-up study (1986–2014) demonstrate that daily intake of five servings of FV has been associated with hazard ratio (95 % CI) of 0·87 (0·85–0·90) for total mortality and 0·88 (0·83–0·94) for CVD mortality[21], with a dose–response meta-analysis of published literature yielding similar results (summary relative risk mortality for five servings daily = 0·87 [95 % CI 0·85–0·88])[21]. However, demonstrating causality within the observational setting is difficult and such confirmation of causality relies on other study designs and ideally intervention studies. Intervention studies requiring long-term dietary change to demonstrate impact on hard clinical outcomes are challenging within nutrition, and therefore intermediate outcomes, such as cardiovascular risk factors, are often utilised[22].

Professor Woodside's group has conducted a series of FV intervention studies[23–28] with a range of primary outcomes, including microvascular function (via venous occlusion plethysmography)[23,25], immune function (vaccine response)[26], oxidative stress and inflammation[27] and insulin resistance (two-step euglycaemic-hyperinsulinemic clamp)[28]. All studies also included a panel of CVD endpoints as secondary endpoints, and therefore an analysis has been conducted aiming to determine the effect of increased FV intake on blood pressure, lipids and C-reactive protein, using data generated from the six separate FV intervention trials where these variables were measured as secondary outcomes.

As the methods in terms of dietary intervention and outcome assessment were conducted using similar methodologies[23–28], secondary analyses of previously conducted FV intervention were possible, although these were not originally specifically designed or powered to address the research questions. The resulting sample size was large and therefore secondary datasets can be a useful resource to address novel research questions, with appropriate consideration of strengths and limitations.

Plant-rich dietary patterns and health: does the type of fruit and vegetable matter?

Professor Eric Rimm, from the Harvard TH Chan School of Public Health, discussed plant-rich DP and

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

health, exploring whether the type of FV matters. His talk was largely based on observational data from the nurses' health study and health professionals follow-up study with repeated measures of diet and follow-up for over 40 years. While evidence for overall FV and chronic disease outcomes is consistent, less evidence exists that has focused on sub-types of FV. The latest meta-analysis, as already presented by Professor Woodside, suggested a maximum benefit of FV intake at five portions daily with a plateau at higher intake levels, with estimates for FV intake being two portions and three portions respectively[21]. The concept of FV variety and whether this is important has also been explored; the conclusion of this analysis was that amount was more important than variety, although statistically this is challenging to comprehensively explore[29]. To look at individual FV is more challenging due to differences in FV consumed across the globe and how these are measured, but to conduct clinical trials with hard clinical outcomes is also unlikely, as Professor Woodside had already observed, so we need to explore and utilise observational data as much as possible.

Professor Rimm discussed the variety in composition of FV in terms of starch and also polyphenol and other bioactives, and asked whether it is reasonable to assume that each type will have similar impact on disease risk. He focused mostly on berries, because of their high polyphenol, and specifically flavonoid, concentrations; flavonoids have a range of biological functions in plants, contributing to colour, flavour and play a role in symbiotic plant–microbe interactions.

Within the Harvard cohorts, dietary intake is assessed via food frequency questionnaires and, while exact intakes may be challenging to measure, these tools can accurately differentiate low or high consumers. Linking intake to NCD risk, there is a difference according to the type of fruit consumed; for example for risk of type 2 diabetes (T2D), fruit such as apples and pears, prunes, grapes and raisins and blueberries were more strongly inversely associated with T2D outcomes than other fruit[30]. Further analysis has looked at change in FV intake and weight change; greater intake of both fruit and vegetables was associated with less weight gain[31]. Genetically associated increased BMI and body weight may also be mitigated by increasing FV intake, with the beneficial effect of increasing FV intake on weight management being more pronounced in individuals with greater genetic susceptibility to obesity. Looking at individual fruit intake, again the flavonoid-rich fruits such as blueberries were associated with less weight gain[32]. The cruciferous and leafy green vegetables and, to a lesser extent, legumes were all associated with less weight gain[32]. Vegetables that were associated with relative weight gain were the more starchy vegetables including peas and maize (and potatoes, although they are not classified as a vegetable in all countries)[32].

Given these associations, it is then of interest to explore whether there are certain compounds which contribute to the observed heterogeneity in association with clinical outcome, with anthocyanins one of the classes of compound studied. Blueberries are a rich source of anthocyanins, and associations with hypertension, T2D, stroke, heart disease and cognitive function have been demonstrated. Based on these observational analyses, a trial was developed exploring the dose–response effects of increased blueberry intake on vascular function and other biomarkers of vascular and metabolic health over 6 months[33]. Clinically significant improvements in robust vascular measures in flow-mediated dilatation and augmentation index were demonstrated which were of a magnitude that would be likely to improve CVD risk.

FV each have their own biological properties and the food group is heterogeneous; many FV have very potent bioactives especially when consumed at consistent levels over time. Professor Rimm concluded that, from a public health perspective just advising people to eat more FV may not be successful and we need to find ways of promoting healthy swaps, for example, communicating the message to eat fewer less healthy foods, to include some FV and replace certain FV with other more bioactive FV.

Plant-based diet quality, plant protein and cardiometabolic health

Professor Frank Hu from the Harvard TH Chan School of Public Health then discussed plant-based diet quality, plant protein and cardiometabolic health. There is strong evidence from meta-analyses of epidemiological studies that a higher intake of plant-based foods is associated with lower risk of hypertension, CVD, cancer and overall mortality, and Professor Hu summarised meta-analyses e.g. of whole grain and mortality[34], nuts, CVD, cancer and mortality[35] and legumes, and inverse associations have been demonstrated for all. Professor Hu pointed out that not all plant-based diets are healthy, as Dr Sun had already demonstrated, and quality is important, whatever the overall DP[36,37]. An example of a new DP approach is exploring the inflammatory potential of the diet – the higher the pro-inflammatory potential of habitual diet has been associated with higher CVD risk[38]. A high pro-inflammatory diet is characterised by a higher intake of red meat, processed meat, organ meat, refined carbohydrates, sugar-sweetened beverages and lower intake of FV, whole grains, tea, coffee and wine; the food which had the strongest anti-inflammatory potential was coffee, which is likely to be due to its bioactive content.

Considering dietary protein type, most of our protein comes from animal sources and less than one-third from plant sources (including legumes, nuts, seeds and some veg). Conventional wisdom is that we need to eat more protein[39] but data from EPIC-Oxford, which compared vegetarians and non-vegetarians, revealed that percentage of energy from protein decreased as degree of restriction of animal protein increased, yet for all participants protein intake exceeded what was recommended[40], so for economically developed countries protein intake is usually adequate. Analysis comparing amino acid composition of animal *v.* plant-based protein suggests that animal protein sources tend to have higher levels of essential amino acids, and plant-based protein non-essential amino acids. Protein sources have been defined in terms of quality based on this distinction, but this does not mean that animal protein sources such as eggs and milk are better quality foods in terms of health outcomes. One misperception is that certain plant foods are entirely devoid of specific amino acids and thus that protein adequacy cannot be supported by plant foods alone. In fact almost all plant foods contain all twenty dietary amino acids and mixed meals that contain a variety of plant foods can make up for the lower levels of certain essential amino acids of individual foods by complementing each other (therefore termed complementary proteins). Professor Hu therefore suggested that it is more useful to consider the protein quality of plant-based meals or diets rather than individual foods[39]. Compared to animal protein, plant protein has been associated with improved insulin sensitivity, lower blood pressure and better lipid profile, with substitution of plant protein for animal protein also related to lower risk of CVD and T2D[41,42]. Furthermore the choice of protein source will inevitably influence other components of diet, including macronutrients, micronutrients and phytochemicals and, therefore, the concept of 'protein package' is very important.

In epidemiological studies it is difficult, if not impossible, to tease out the health benefits of plant protein from other components of plant foods; plant protein-rich DP are a continuum rather than a dichotomy, because few vegetarians or vegans are included in existing cohort studies. Dietary intervention studies have tested plant foods such as nuts and whole grains and isolated plant proteins (soya, pea) on cardiometabolic biomarkers such as blood lipids, blood sugar and blood pressure (e.g.[43]). In both epidemiological studies and intervention trials, the replacement foods or macronutrients are important. It is also critical to look at plant-based foods and DP through both health and environmental lenses.

Meta-analyses of randomised control trials of plant foods on blood lipids – tree nuts, walnuts, almonds, soya protein and pulses have all been shown to be effective on a range of lipids, e.g. LDL-cholesterol has been reduced by 5–10 % which is clinically meaningful, i.e. such a reduction would likely lead to a reduction in CVD risk[44]. Such an estimate has been supported by a series of interventions with the portfolio diet, which includes 45 g nuts daily, 50 g plant protein, 30 g viscous fibre and 2 g plant sterols, with a 30 % reduction in LDL demonstrated compared to a control diet[45]; such a reduction is comparable to a statin.

Analysis of the Harvard cohorts shows that animal protein intake is slowly decreasing over time while plant protein is increasing[46]. Higher consumption of animal protein is associated with increased risk of T2D, with the opposite being the case for vegetable protein[47], and a similar trend has been observed for CVD mortality[46]. Estimating the effect of replacing 3 % of energy from animal sources by plant protein was estimated to reduce mortality[46]. An inverse association between isoflavone intake and risk of CVD in the cohorts has also been observed, and these are found in soya protein products[48]. The investigators also explored the impact of substituting one serving daily or other protein sources (including fish, poultry, nuts, legumes, low-fat dairy and whole grains) for one serving red meat daily and this substitution was associated with a 7–19 % lower mortality risk. It was estimated that 9·3 % of premature deaths in men and 7·6 % in women could be prevented if all individuals consume fewer than 0·5 servings daily (42 g red meat daily)[49]. Such data suggest the potential of major health benefits as a result of small dietary shifts without promoting the complete avoidance of meat.

Metabolomic approaches have identified metabolites that discriminate between animal protein and plant protein-rich diets and higher concentrations of plant protein metabolites such as glycine and glutamine have been associated with reduced cardiometabolic risk[50]. A recently published paper looked at host and gut microbial tryptophan (derived from animal protein) metabolism and T2D risk has supported the suggestion that the effects of fibre-rich diets on beneficial metabolites are partly mediated through gut microbiome composition[51].

Professor Hu finished with a discussion about plant-based meat alternatives and whether they can be part of a healthy and sustainable diet[52]. These are products made from plant protein and engineered to mimic the taste and texture of meat. The suggestion is that the environmental impact of these products will be lower, but the nutrient composition is often not optimal, with high amounts of sodium and saturated fat in many of these highly processed products. Haem iron also tends to be added to many of these products and a higher haem iron intake has been associated with increased body iron stores and risk of T2D. Recently a crossover trial of plant-based meat alternatives has been conducted over 8 weeks; trimethylamine-*N*-oxide was reduced as LDL-cholesterol and body weight during this time[53]. These results are encouraging but further research is required in larger studies and over longer duration. To conclude, Professor Hu suggested that not all plant foods and plant-based diets are healthy and that when exploring these diets it is important to look through both health and environmental lenses. All protein sources are also not equal – an approach to better dietary choices is to eat a little less red meat, and enjoy more variety by incorporating minimally processed plant-based protein sources such as beans, nuts, whole grains and lentils. The protein package is important; plant-based protein sources have other beneficial nutrients and bioactive compounds and it may be prudent to include grains with higher protein:starch ratio (oats, quinoa, barley, brown rice). Technological innovations such as plant-based meat alternatives and lab grown meat have the potential to reduce the environmental impact of the food system but their longer-term impacts on human health remain to be seen.

European children's eating habits with a focus on fruit and vegetable intake

Dr Mirjam Heinen, from the WHO, started the second day by describing European children and adolescents'

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

eating habits with a focus on FV. She reminded the audience that optimal nutrition is essential for achieving several of the sustainable development goals and that many sustainable development goals impact nutrition security, hence nutrition is linked to goals and indicators beyond goal 2 which addresses hunger[54]. The WHO-defined European region includes eastern European and some Asian countries and the region is strongly affected by challenges imposed by the overconsumption of foods high in salt, fat and sugar and the underconsumption of FV. Unhealthy DP account for a large share of the NCD burden in the region.

The WHO has two large surveillance studies that collect data in children and adolescents. The first, the Childhood Obesity Surveillance Initiative, collects data in primary school children[55] and measures trends in underweight, overweight and obesity in primary school children (6–9 year olds) at regular intervals. It aims to fill the gap in available inter-country comparable anthropometric data of primary school children using measured weight and height; this allows understanding of progress, monitoring of policy response to the obesity epidemic, encourages the countries involved to share experiences and resources and addresses the needs of public health programmes, avoiding duplication of effort in terms of data collection. Mandatory items include measured weight and height and some school environment characteristics; optional items include waist and hip circumference, physical activity, co-morbidities, family socioeconomic status and dietary intake patterns including fresh fruit (excluding fruit juice and dried fruit) and vegetables (excluding potatoes). Since its launch in 2007, Childhood Obesity Surveillance Initiative's participation rates have increased from thirteen to forty-three countries, including those outside of the EU. The number of children included in round 4 (2017/2018) is about 400 000, and, based on this population, 29 % of boys and 27 % of girls were living with overweight or obesity (one in ten with obesity)[55]. There was marked variation in breakfast eating frequency and sugar-sweetened beverage consumption across countries; similarly for fresh fruit, just under 50 % of children reported consuming fresh fruit daily, but this varied from 18 to 80 %; overall only nine countries out of twenty-three included more than half of children reporting daily intake[55]. Girls reported more frequent consumption than boys. For vegetables, less than 30 % reported daily intake, with this ranging from 74 % in San Marino to 9 % in Spain. Overall, only four out of twenty-three countries had >50 % of children reporting daily vegetable intake[55]. As for fruit, girls were more likely to eat vegetables daily compared to boys[55]. In terms of availability in schools, there was variation across the region, with some countries having fruit available free of charge in the majority of schools and in a minimal number of schools in other countries[55].

The odds of not consuming fresh fruit daily by parental education was calculated and children whose parents had lower education status were more likely to not eat fresh fruit daily *v.* those with higher parental education (adjusted pooled OR 1·48 (95 % CI 1·29–1·70)). A similar association was observed in terms of family perceived wealth (adjusted pooled OR 1·83 (95 % CI 1·64–2·04)), but the picture was less clear according to parental employment[56]. For vegetables, similar patterns were seen for parental education (adjusted pooled OR 1·36 (95 % CI 1·18–1·57)), and for family perceived wealth (adjusted pooled OR 1·37 (95 % CI 1·20–1·57)) and either a weak or no association was seen in terms of daily vegetable consumption and parental employment. In terms of urbanisation of school location, no significant associations were found in two out of three countries and in the remaining countries results were mixed with small effects[57].

The second surveillance study presented by Dr Heinen was the health behaviour in school-aged children study conducted in adolescents[58]. It is a cross-national research study and every 4 years data are collected on 11-, 13- and 15-year olds' health and well-being, health behaviours and social environments with an aim of gaining new insights into young people's health and well-being, an understanding of the social determinants of health to inform policy and practice to improve young people's lives. The survey was started in 1983–1984 when the first health behaviour in school-aged children survey was conducted in five countries and the last study included forty-five regions across Europe and North America in 2017–2018.

The proportion of adolescents who eat neither fruit nor vegetables daily varies between <30 % (Albania) and >60 % (Finland), with a mean of 48 %[58]. Girls are more likely to consume both FV than boys, and the proportions of consuming these food groups decrease as children get older. Furthermore, the most affluent adolescents were more likely to eat both FV daily[58]. Although no social inequalities were observed for fruit in Sweden and Norway, such inequalities were observed in all other countries and in all countries for vegetables[58]. A statistically significant inverse correlation was observed between overweight and obesity and vegetable intake[58].

Overall these surveys have revealed a low intake of fruit and even lower vegetable consumption. This can lead to so-called hidden hunger or deficiency in micronutrients and will influence risk of NCD. As adolescents grow older and gain more autonomy over their earing behaviours they will be more likely to make unhealthy food choices. Social inequalities in eating behaviours are observed in many countries/regions, with children and adolescents from more affluent families generally having healthier eating habits. This leaves children and adolescents from lower socioeconomic status backgrounds vulnerable to poor nutrition and associated adverse health outcomes. This is important when addressing strategies, policy actions and interventions targeting social inequalities in children and adolescent diets. The WHO has several policies aiming to address these issues, including guidelines being developed on policy actions to improve the food environment, focusing on school food and nutrition policy guidance, with recommendations on school food standards, school food provision, positive reinforcements (nudges) and marketing restrictions in

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

schools[59]. These data have also led to an action plan devised to combat childhood obesity in Europe and beyond[60]. The WHO is also working on a healthy and sustainable diets series of workstreams, with the aim of gathering evidence to inform the development of policy guidance in this area. Activities include a systematic literature review of intake and adequacy of vegan diets, and a future multi-country study on the nutritional content of vegan burgers. A study looking at the nutritional content and environmental impact associated with processed plant-based food products from online supermarkets has just been published[61], which indicates the WHO's interest in this area.

Plant-rich diets and cognitive health during ageing

Dr Claire McEvoy, from the Centre for Public Health at Queen's University Belfast, then discussed the evidence supporting a role for plant-rich diets and cognitive health during ageing. There is an increasing burden of dementia in the UK and globally, being a leading cause of disability and loss of independence that is expected to triple in the next 30 years in almost every country in line with population ageing. Age is the biggest risk factor for dementia, and Alzheimer's disease (AD) is the most common type of dementia, with the development of amyloid plaque as a key pathologic feature of that condition.

It has been estimated that up to 40 % of dementia could be delayed or prevented by targeting modifiable risk factors, particularly cardiometabolic-linked risk factors. Plant-rich diets could play a role and three plant-rich DP have been mainly examined to date: the Mediterranean diet (MD), the dietary approaches to stop hypertension diet and the Mediterranean–dietary approaches to stop hypertension intervention for neurodegenerative delay diet. These DP differ (e.g. in terms of fat source, alcohol intake) but are all rich in vegetables, legumes, whole grains and nuts and are low in red meat. The Mediterranean–dietary approaches to stop hypertension intervention for neurodegenerative delay diet is hypothesis driven and was developed with brain health outcomes in mind; in terms of FV it includes a focus on green leafy vegetables and berries rather than total FV intake.

Both the MD and Mediterranean–dietary approaches to stop hypertension intervention for neurodegenerative delay diets have been examined in relation to cognitive impairment in the US health and retirement study. In 5907 cognitively healthy older US adults, aged on average 68 years, high adherence to an MD or Mediterranean–dietary approaches to stop hypertension intervention for neurodegenerative delay diet was associated with 30–35 % lower odds of cognitive impairment, after adjustment for potential confounders including cardiovascular risk factors, suggesting that adherence to these DP could help preserve cognition[62]. A meta-analysis of prospective data supported a protective role for the MD on cognitive decline in older adults, although there was substantial heterogeneity between the studies, which may reflect variation in exposure and outcome measure data collection[63]. A further meta-analysis explored the association between plant-rich DP and dementia risk; high adherence to a plant-rich DP was associated with a lower risk of overall dementia and AD, but no association was found with MD specifically and risk of overall dementia in non-Mediterranean countries[64].

It is known that diet is a modifiable life-long exposure but most studies have been conducted exclusively in older populations using one dietary exposure measure that is unlikely to reflect long-term dietary intake, and with a relatively short follow-up time. AD has a long preclinical phase and it is possible that brain changes in the preclinical stage of AD elicit changes to dietary habits. Hence, reverse causation could impact findings from current epidemiologic studies in older populations. The coronary artery risk development in young adults study attempted to deal with this as both diet intake and cognition were repeatedly measured earlier in life. In coronary artery risk development in young adult participants, MD was associated with less than 5 year decline in global cognitive function, particularly better preservation of executive function. In contrast, no association was observed for the dietary approaches to stop hypertension diet[65]. This suggests that the MD may be neuroprotective in mid-life. Only a few intervention studies have tested this hypothesis, again with variation in outcomes and duration of intervention and of follow-up. For example, a post-hoc analysis of the Prevención con Dieta Mediterránea study demonstrated a modest beneficial effect of adherence to an MD supplemented with nuts or olive oil over 4–6 years on cognitive function, particularly global cognition and memory[66].

Cognitive changes are subtle and may be difficult to measure using standardised cognitive testing, particularly in cognitively healthy adults. Examination of neuroimaging biomarkers could help to elucidate potential mechanisms of diet on AD but few prospective studies have both dietary intake and neuroimaging data available. The Lothian birth cohort is one such study that reported a positive association between increased MD adherence and less total brain atrophy over 3 years, and these effects were significant even when adjusting for education and childhood intelligence quotient suggesting a causal effect of diets on brain volume beyond that of healthier lifestyle choice in more educated persons[67]. Other studies have demonstrated associations between increased MD adherence and lower amyloid accumulation, with an estimated 3·5 years protection against AD through modelling of collected data[68,69].

As cognitive decline and dementia are complex conditions with multiple risk factors, multi-modal or component interventions are thought to be more likely to be successful at reducing risk. The Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) study[70] in Finland tested the effect of diet, exercise, cognitive training and vascular risk monitoring on cognitive outcomes, with the dietary advice, which was personalised, including following a Nordic diet, having more than 400 g FV daily, eating whole grain foods, low-fat milk and meat, having <50 g sucrose daily, using rapeseed oil as a fat source and

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

consuming fish more than twice weekly. The dietary advice was intensive involving both individual and group sessions. Significant effects were demonstrated on the primary composite cognitive score as well as secondary outcomes including executive function, processing speed and memory[70]. Participants in the intervention had not only lower risk for cognitive decline, but also a 30 % lower risk of functional decline and better health-related quality of life, compared to those in the control group[71,72]. However, when researchers looked at diet alone, it was associated with favourable changes in executive function but not memory or processing speed, nor global cognitive function[71,72]. The FINGER trial is being adapted and tested in other populations via the worldwide FINGER network, to determine whether the FINGER study can be replicated in other diverse populations and clarify the necessary components and optimal doses to include in the multicomponent interventions. Other research questions include whether the interventions can be delivered using low cost and scalable approaches, and whether cultural adaptations to the dietary and other lifestyle behaviours are required.

Dr McEvoy concluded that plant-rich diets are associated with slower cognitive decline and reduced dementia risk, particularly AD. The ideal combination of foods and nutrients for neuroprotection is not yet clear as few DP have been tested. Intervention studies are needed to examine the effects of dietary modification on clinically relevant endpoints and explore the use of neuroimaging and AD blood biomarkers; these should be considered as capturing cognition outcomes in cognitively healthy participants is challenging. Finally, combining plant-rich diets with other lifestyle factors may be more effective in slowing cognitive decline.

Dietary patterns and CVD and mortality: use of UK Biobank

Dr Carmen Piernas from the University of Oxford described analyses of the association between DP and CVD and mortality using the UK Biobank study. Dietary risk factors for NCD include low whole grains, legumes, nuts, fruit, fibre, vegetables, high red or processed meats, *trans* fat and sodium[73]; these dietary risk factors can be combined and overall DP examined which allows the synergistic effects of many dietary risk factors to be accounted for. Since dietary risk factors tend to cluster, moving away from single nutrient and food group analysis makes sense in terms of how we eat, although to date dietary guidelines do tend to still focus on single foods, food groups and nutrients. From a research perspective, exploring DP allows for the assessment of the cumulative exposure to different dietary components and as such, these DP may have stronger effects on health than any single component[74].

Dr Piernas and colleagues have examined DP and incidence of total and fatal CVD and all-cause mortality in the UK Biobank (*n* 116 806), utilising a prospective cohort design for the analysis. They used reduced rank regression to calculate the DP, which tries to identify combinations of foods which explain high variability in nutrients of concern (dietary energy density, free sugars, saturated fat and fibre), determining the links between predictor variables (food groups), identified response variables (nutrients) and outcomes (CVD fatal and non-fatal and all-cause mortality)[75].

The UK Biobank study recruited about 500 000 volunteers aged 40–69 years between 2006 and 2010 from twenty-two assessment centres across England (89 %), Scotland (7 %) and Wales (4 %). Comprehensive baseline data collection included lifestyle and environmental factors, personal and family medical history, cognitive function, physical measurements (height and weight) and biological samples (blood, saliva, urine). Consent was given by participants for UK Biobank to follow their health through medical records including linkage to hospital admissions and death records and also to be recontacted for further data collection. Dietary intake was assessed using the 24 h Oxford WebQ collected at the baseline assessment and up to four times with links distributed by email. Participants who provided a minimum of two dietary questionnaires were analysed, and all reported foods and beverages were classified into fifty major food groups[75]. The first dietary pattern (DP1) explained 43 % of overall variability which was associated with higher intakes of energy dense foods, SFA and free sugars and lower intake of fibre[75]. DP1 was characterised by high intakes of chocolate and confectionery, butter and low-fibre bread, and low intakes of fresh FV. Dietary pattern two (DP2) explained 20 % of variability and was characterised by higher intakes of free sugars but lower intakes of SFA, in particular by high intakes of sugar-sweetened beverages, fruit juice, table sugars and preserves, chocolate confectionery; and low intakes of high-fat cheese, butter and other animal fat spreads. DP1 was positively associated with total CVD, fatal CVD and all-cause mortality, while DP2 displayed a non-linear association with the same outcomes and associations were only statistically significant at the higher end of the distribution. DP1 was significantly associated with BMI and diastolic blood pressure (DBP), a slight positive association was observed with LDL, a negative association with HDL and no association with systolic blood pressure (SBP) and HbA1c. For DP2 there was no association with BMI, DBP, SBP, HbA1c or LDL and but there was a negative association with HDL[75].

Aside from investigating DP, the investigators also looked at adherence to dietary recommendations in a separate analysis of the same population[76]. WHO recommendations were used, these were: intake of saturated fat <10 % energy, intake of free sugars <10 % energy, greater than or equal to five portions FV daily and >25 g fibre daily[76]. About 69 % of participants met either none or one of these four recommendations, with the fibre and FV recommendations being the most poorly adhered to. Adherence was clearly related to all-cause mortality, but this was less clear for total and fatal CVD, with statistically significant reductions in risk only being found for those who met three or four recommendations. The only individual recommendation

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

that was significantly associated with all-cause mortality was the five servings of FV daily; no recommendation was associated with the total and fatal CVD outcomes, while the analysis examining CVD risk factors as outcomes was mixed[76].

In summary, Dr Piernas concluded that DP identified among UK adults are associated with health risk, and poor adherence to major dietary recommendations is common in this population. The analyses conducted support the evidence base for food-based dietary guidelines and support current recommendations to limit foods high in saturated fat and free sugars and to increase FV intake and fibre.

Health impacts and environmental footprints of plant-rich dietary patterns

Dr Pauline Scheelbeek from the London School of Hygiene & Tropical Medicine then shifted attention to focus on the environmental footprints of plant-rich DP and the impact on health and environmental sustainability of major population-wide shifts towards more plant-based DP.

Increased uptake of predominantly plant-based diets would result in a scaling down of production of animal-sourced foods (to match the declining demands), and would likely have direct and indirect effects on both environment and health. Direct effects on the environment would arise from the corresponding reductions in food system-related greenhouse gas emissions, water footprints, land use and eutrophication rates. Indirect effects include a reduction of air pollution (e.g. fine particulate matter), a reduction in emerging zoonosis (diseases that can be spread between animals and human subjects) and the prevention of biodiversity loss. The impact on population and individual level health outcomes of increased uptake of predominantly plant-based diets will vary greatly and will be determined by healthfulness of initial diets, as well as initial exposure to environmental hazards. Current global food systems do not deliver on the health front, with high levels of underweight, stunting, overweight and obesity and anaemia[77], and moves towards a plant-rich DP, rich in FV, could help achieve improvements in some of these health outcomes, including helping to improve intake of key nutrients, while reducing for example the intake of saturated fat and sodium[78].

A number of studies have explored the potential environmental impacts of following a predominantly plant-based diet. Vegan, vegetarian and flexitarian diets are often associated with lower impacts on greenhouse gas emissions and land use compared to diets richer in animal-sourced foods[79]. However, at individual food level, carbon footprints of both animal-sourced and plant-based foods can vary considerably depending on farming production and management methods and source of the inputs (i.e. feed[80]). In areas where agriculture is the main source of air pollution-related morbidity (such as in large parts of Europe), population-wide changes to more plant-rich DP and associated reductions in animal-sourced food production could therefore also substantially improve population health by consequential improvements in air quality[80]. Water use, however, is not necessarily lower for vegan and vegetarian DP particularly where nut or heavily irrigated fruit consumption is high. Sourcing such foods from water-scarce areas may increase water supply problems and could lead to substantial negative public health impact in low-income countries. At the same time, major water savings could also be achieved through the reduction of animal-sourced food production, particularly related to feed. For example, soya used for feed in China is often produced elsewhere and includes highly water-scarce production areas. This global dimension is not always considered in footprint calculations, but could cause serious water-scarcity threats and needs to be considered in detail.

Various research groups have modelled the likely impact of different DP on health outcomes, premature mortality and environmental impacts, suggesting improvements to all when shifting from current to (e.g.) flexitarian or vegan diets[81]. However the drivers of these health and environmental improvements seem to vary, with the health improvements largely arising from reduced energy intake and reduction of overweight/obesity, while the changes in environmental impact were driven by changing demands (and hence production) of plant-based *v.* animal-sourced foods[81].

Dr Scheelbeek suggested that we already know ‘more or less’ what a future DP should look like – especially in food secure areas in the Global North. The EAT Lancet report is one example of a suggestion of what such a diet should look like[82], however very few people currently adhere to such diets. Some national dietary guidelines also include sustainability aspects: better adherence to the Eatwell guide for example (the current UK dietary guidelines) would have co-benefits for the environment, even though this was not a focus of the recommendations when they were developed.

As awareness of the environmental impact of different dietary choices increases, new products are being developed. Plant-based meat and dairy alternatives intake is increasing, particularly in younger populations, but the impact of these new foods and food products is as yet uncertain.

While it is clear that more profound changes are needed to national food systems and diets to deliver on health targets and meet the Paris agreement on climate change, resilience and externalities should also be considered. If everyone in the UK met the five servings FV daily intake target then there would currently not be enough FV supply produced within the UK to support this. Options to increase the supply include expanding domestic production, which may also have positive impacts on biodiversity. However, offering more locally produced FV may not align with current demand of specific exotic varieties that are increasingly consumed by the UK population, while ‘traditional’ varieties (such as cabbage and peas) are becoming less popular over time[83]. Another alternative is to import more FV. Looking at current trade patterns, this strategy would involve importing FV from a range of climate change-vulnerable countries, and that trend is increasing: current UK supply from climate-vulnerable countries was estimated to be 37 % compared to 20 % in 1987[83].

Dr Scheelbeek ended her talk with a discussion of food waste as plant-based foods are often more perishable than other foods[84] and therefore aiming to increase plant-based foods within our diet may, without any interventions, have implications for food waste, which would reduce the gains in terms of environmental footprints of these predominantly plant-based diets.

Plant-rich dietary patterns, animal-sourced foods, health and agri-food systems

Professor Jonathon Rushton, University of Liverpool, discussed plant-rich DP, animal-sourced foods, health and agri-food systems. The premise of his presentation was that food systems produce food, culture, employment and business opportunities that are the basis for the health and wellbeing of people in societies across the world, but they are also capable of generating negative externalities in terms of effects on public health and the environment. The negative externalities have become a major focus in recent years, with increasing pressure for behaviour change (e.g. a shift to a more plant-rich DP to improve health and/or reduce environmental impact) but Professor Rushton argued that systemic failure in the food system cannot be overcome with behavioural change alone; the two things cannot be done in isolation. Professor Rushton suggested that the food system itself creates the diet we eat so we also have to understand the food system and how it operates.

Concerns about livestock and the environment have been emerging since the 1980s although there are still methodological debates about the real impact, for example, of estimated greenhouse gas emission from the livestock section and there is an ongoing debate on how to measure methane[85] and understanding the source of ongoing increases in methane emissions. On the nutrition side there is still ongoing debate about many issues, e.g. fat source and NCD risk[86]. Set against this, in the past decade there has been a rise in the vegan movement, with its allied messaging on climate impact, health and improved animal welfare. The vegan movement has been around for a much longer period of time yet there has been a recent growth in the effectiveness of its messaging and interest in why this might be. In a BNF YouGov survey in 2020 when asked what a plant-based diet meant to respondents, the most common response was a vegan diet (41 %)[87].

Professor Rushton suggested there is a strong link between this messaging, the food system itself and the food companies that make up that food system. Forces underlying the changes in messaging and ultimately behaviours are linked to supply and demand within the food system and the attitude to profits of food companies. Companies in the food system are generally stock-listed and therefore report and respond to the stockholders – they are primarily profit driven and these profits depend on how markets and prices are regulated; they do not respond to any great extent to the externalities such as public health and the environmental impacts. A sudden surge in plant-based meat and milk alternatives has occurred but not necessarily driven by health or environmental concerns, although these may be the concerns of some consumers, For example, milk is the second most important commodity in the food system in terms of total economic value yet it is a low value product, in contrast the rapid rise of alternative milk products can in part be explained by the highly profitability of such products to food companies. Similarly lab-grown meat and plant-based meat substitutes are higher priced and potentially of interest for food companies who are happy to push a message to move away from animal-sourced products.

This background and context then presents a problem. There is now clear messaging that animal-sourced foods are bad for the environment, for health and animal welfare. The switch to plant-based diets seems obvious as there appear to be so many wins, yet the evidence as to whether such a population shift will have the desired impacts has yet to be demonstrated. Professor Rushton explored this question by providing an overview of how he sees the livestock sector and its development.

Key messages are that meat and other livestock products need to be treated as an issue of supply and demand of inputs and outputs. The supply is complex because of the changes in the way animals are fed and raised and how they are processed.

Historically, in a field example from the Bolivian Andes, pigs play an important role in recycling crop residue and a role in family structure. When there is surplus of locally grown maize grain and prices go down, the surplus maize is fed to the pigs; this is a way of adding value to the maize. When maize is scarce and prices go up, the maize is shipped to urban centres as grain for human consumption. There is, therefore, a balance between the production of meat and grain and the supply and demand for grain limits meat consumption; this local example is one that would have been true to many populations 50 years ago and to the majority 100 years ago.

Thinking on a more global scale, the reaction to the food shortages and famines during the 1940s, 1950s and 1960s was a search for improved grain production; the resulting agricultural revolutions led to an explosion in grain production, largely through increases in crop yields and expansion of oil seed crops across the world. These are multipurpose crops (principally soya and palm oil) providing feed for animals, oil for the food industry, cooking oil and fuels. Again there has been rapid expansion in the production of these crops and resulting vegetable oils, some through the expansion of cropped areas, deforestation but also through increases in crop yields.

The changes afore-mentioned led to grains being in plentiful supply; oil seed cakes started to be made available and human populations increased, became urbanised and got wealthier, which also led to a livestock revolution[88]. Livestock units have increased, with the some increase in cattle with associated concerns on methane production, but a large increase in poultry. Poultry meat production has also doubled over the past 15 years, achieved partly by increasing poultry

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

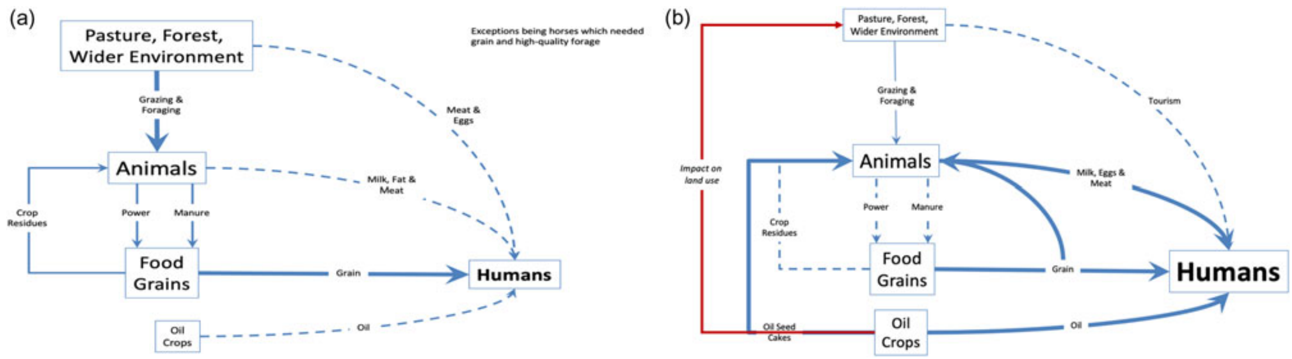

Fig. 1. Traditional (a) and modern (b) food production systems, illustrating the strength of links between the different elements of the system, with changes occurring as a result of agricultural/crop revolution.

population, but also significant evolution in the types of birds and their breeding, impacting individual bird size. Livestock husbandry and feeding regimes have also developed over time, moving from predominantly grazing and scavenging systems to highly managed forage and conservation systems and sophisticated housing and handling systems, with feeding of concentrates. Such changes have led to a dramatic increase in output per animal and per bird space and therefore increased efficiency. The changes in food production systems are illustrated in Fig. 1.

These two crop revolutions have also been accompanied by animals becoming less relevant as a source of power due to the introduction of the combustion engine and non-renewable fossil fuels, allowing larger tracts of land and different soil types to be cultivated. This has been accompanied by less dependency on animal manure which has largely been replaced by chemical fertiliser. All of these have led to the availability of cheap food and feed grains which has changed the role of animals in the farm, and has had an impact on both animal and human diets.

Alongside these dramatic changes in animal production and nutrition there has been a total transformation in food processing[(89)], with much of the preparation of food and cooking now done outside the home and processed food dominating in the UK diet. Crop and livestock products are transported and processed long distances from cities and towns; and what is purchased has changed, for example, a shift from whole chicken through to processed breast meat in the form of nuggets[(89)]. Looking at the nutrient composition of the different parts of a chicken reveal a problem in that the nutrient composition does differ depending on the part of the chicken being consumed, particularly in terms of micronutrient composition[(89)].

Thus there has been rapid increase in meat supply, more than doubling per person since 1950. Much of this increase has been achieved through species selection, genetic changes, health improvements and nutrition with feed grains and oil seed cakes. At the national level there is variation in the increases in terms of meat type but tends to be dominated by poultry; in summary we have moved from a grass-based to grain-based meat eating population within a generation.

Therefore through a mixture of crop productivity, animal nutrition and production changes the supply of meat and livestock products has increased. There has also been a shift in the relevant costs of meat production by species and the relative price of livestock products in general has decreased relative to other foods and services in society. People are spending less on meat as a percentage of their shopping baskets (from about 8 to 3·5 % in around 40 years). The low prices have encouraged food companies, who are driven by product margins, to use animal-based ingredients in their processed foods. Increasingly meat is not purchased as a product we prepare at home but as a product in ready meals and convenience meat products.

Professor Rushton reflected that livestock play a central role in food systems. They use crop residues, agricultural by-products and land areas that are difficult to use for producing food for direct human consumption. In the past there has been a balance and a relative scarcity of livestock products for consumption, but over the past 60 years that balance has been broken, leading to greater availability of livestock products at cheaper prices. If we are to manage the problems this create we need to look at the systemic problems in supply and demand as well as individual behaviour change.

We do have to be cognisant of the fact that restricting or eliminating animal-sourced food from the diet and adopting plant-based DP, this will make it more difficult to get adequate amounts of some nutrients, particularly if people are not eating a diverse diet[(90)]. Professor Rushton suggested there needs to be a balance around this and animal-sourced foods should be eaten as part of a plant-based diet that also has a good proportion of FV. Animal-sourced foods can provide both high quality protein and a range of micronutrients. Plant-based meat and dairy alternatives are highly processed with long ingredient lists and can be costly; therefore there are potential issues with direct replacement of animal-sourced protein with plant-based sources, and protein source and amino acid composition will be important, which Professor Hu had already discussed. Therefore, replacing processed meat products with processed plant-based products is unlikely to solve public health issues and may make them worse as these replacement products have variable protein and micronutrient content.

Professor Rushton's hope is that we move to a plant-dominated DP with contributions from animal-sourced foods, with accompanying changes to animal production systems. Cattle numbers have not substantially changed to explain the recent exponential increases in methane emissions; there have to be other explanations. We also need to consider the grain and oil seeds used for livestock feed generally. These crops need to be directed to people, with land returned to forest to deliver environmental benefits. He cautioned that we must not fall into the trap of focusing only on the environment; negative public health impacts also need to be considered.

Food insecurity and relation to fruit and vegetable intake

The last speaker, Dr Hannah Ensaff from the University of Leeds, presented the evidence with regards to food insecurity and FV intake. Dr Ensaff defined food insecurity, outlined its measurement and what we currently understand based on systematic reviews of food insecurity and FV intake, before ending with some thoughts on future directions. This was all against a backdrop of insufficient FV intake globally, which is a major risk factor for global disease and mortality burden.

Increases in the prevalence of food insecurity have been reported in many countries, including the UK, alongside austerity and welfare changes[91]. It has been estimated that 43 % of UK households in receipt of universal credit are food insecure[92]. Food insecurity has also been linked with stagnant wages and increased cost of living[93], which clearly includes food, in addition to fuel and childcare costs.

The challenge of already low FV intake and climbing food insecurity highlights the importance of understanding how food insecurity may influence FV intake. Furthermore, considering health equity and the continuing health inequalities[94], there is the likelihood that those for whom diet is the most critical or relevant are the ones for whom food security is the most precarious.

Essential to food security are the issues of food availability, accessibility and affordability[95], with individual households being able to access and afford the food that they need. The FAO of the UN has defined food security as 'physical, social and economic access to sufficient, safe and nutritious food' to meet an individual's 'dietary needs and food preferences for an active and healthy life'[96]. Conversely, food insecurity, sometimes referred to as food poverty, relates to 'household-level economic and social condition of limited or uncertain access to adequate food'[97], and may relate to lack of 'availability of nutritionally adequate and safe foods' or lack of 'ability to acquire acceptable foods in socially acceptable ways'[98]. As well as food insecurity relating to difficulties accessing sufficient nutritious food, the importance of food preferences[96] and socially acceptable means of acquiring food[98] are recognised, implying for example, not having to resort to emergency food aid or scavenging.

Food insecurity is a public health concern globally; although rates of severe food insecurity are highest in low and middle-income countries, increases have been observed in high-income countries, and food insecurity is a public health priority for countries such as the UK, USA, Canada and Australia[99]. Indeed, food insecurity is substantial and growing in the UK, where rates are among the worse in Europe[100]. There are increasing concerns due to the number of households affected and the impact on public health and disease prevention, which ultimately points to serious public health implications[101].

Food insecurity is assessed by a number of measures including the food insecurity experience scale[102] from the FAO and the United States Department of Agriculture adult food security survey module[103]. Items related to behaviours and/or experiences of difficulties in meeting food needs, with the measure of severity based on the number of behaviours and experiences reported. Although the tools used and timeframe assessed can vary, the need to measure food insecurity has become evident, not least because of the need to monitor changes over time. This will allow critical data accumulation over a number of years, and supports the requirement to measure food insecurity with respect to the UN sustainable development goal (indicator 2·1·2 prevalence of moderate or severe food insecurity in the population).

In the UK, items from measures such as the FAO food insecurity experience scale and the United States Department of Agriculture adult food security survey module are used in the Family Resources Survey[104], The Scottish Health Survey[105] and the Food and You 2 Survey[106]. Data collected using the food insecurity experience scale indicate a 3 year average (2018–2020) of 3·9 % food insecurity at the moderate or severe levels (0·7 % at the severe level); this translates to 2·6 million people living in households where one or more members is moderately or severely food insecure[107]. The Food and You 2 Survey data on food security (November 2020–January 2021 for England, Wales and Northern Ireland) indicate the prevalence of marginal, low and very low food security to be 11, 8 and 7 % respectively[108].

Food insecurity is associated with socioeconomic status, with factors such as household income, working status and education relevant[109,110], similarly, social networks and social capital have been found to be relevant[110], as has perception of financial insecurity[111].

Money spent on food, unlike some other expenditures, can be adjusted to some extent, and food insecurity can influence food choice and individual dietary intake; accessibility to nutritious foods is critical and a prerequisite to an adequate diet. A number of studies have examined associations between food security and diet quality. Food insecure individuals can have poorer quality diets independent of poverty and sociodemographic differences[112], with food sources also used differently and the diet quality of foods sourced from grocery stores higher in those individuals that are highly food secure individuals[113]. Further, the percentage of energy from

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

ultra-processed foods has been reported to be strongly related to the severity of food insecurity – the more severe the food insecurity the higher the ultra-processed food intake and lower the diet quality[114].

Dr Ensaff then looked at systematic reviews which have focused on food insecurity and FV intake specifically. The first demonstrated that diet quality was lower for food insecure adults, and food insecurity was associated with lower FV intake[115]. For children, the evidence was less consistent with the suggestion that parents were shielding children from their food insecurity and protecting their children's intake[115]. The second review focused on food insecurity and women's dietary outcomes, and reported FV in eleven out of twenty-four studies, with nine of these reporting that food insecure women consumed fewer servings of FV compared to food secure women, and in five of the nine studies, these differences were statistically significant; there were two studies that were considered high quality and both of these found a difference in FV intake between women who were food insecure and secure[116]. A further systematic review focused on food insecurity and dietary outcomes in university students; in most of the studies reviewed (i.e. four of the six studies with measures of fruit intake; four of the seven with vegetable intake; and five of the six with total FV intake) lower intakes were evident among food insecure students[117]. Again, the higher quality studies confirmed these associations and authors also pointed to the vulnerability of university students to food insecurity, who may, as a coping strategy, omit foods such as FV or whole grains. Interestingly a protective effect of living in catered-for accommodation was also pointed to.

Turning to specific studies, secondary data analysis of the Food and You Survey data in the UK suggested that there was an association between food insecurity or financially driven food changes, and the likelihood of reporting lower FV intake, with both of these being independent significant predictors[118]. For every unit increment in the Food Security Score (i.e. being more food insecure) there was an 11 % reduction in the odds of being a high FV consumer, and with every increment in financially driven food changes score there was a 5 % decrease in the odds of being a high FV consumer, in multivariable adjusted models[118]. Similar findings for UK data from the international food policy study were shown, where the odds of consuming FV were lower for food insecure adults (although for fruit juice, this was higher)[119].

Finally, an analysis of data from the Born in Bradford cohort study highlighted the importance of ethnicity and context. Vegetable consumption was higher for Pakistani-origin and for White British mothers who were food secure compared to those who were food insecure[120]. Fruit consumption was, however, higher for Pakistani-origin mothers who were food insecure compared to those who were food secure. Authors attributed this potentially to a combination of cost and cultural norms, and also highlighted the relevance of community support to how food insecurity is experienced[120].

Dr Ensaff reminded the audience that an impact of the global pandemic on food insecurity has now been widely demonstrated, and as COVID recovery continues we are yet to know the true impact. However, evidence points to a worsening picture for many families financially and the need for intervention. She concluded with three key aspects in terms of future directions for research. First, with the need to mitigate against food insecurity and its detriment, strategies and interventions that are targeted where they are most needed will become more critical. There are a number of examples of such interventions including *Eat San Francisco Vouchers for Veggies*[121] and *Food Justice Truck*[122]. Secondly, future work to incorporate more aspects of food insecurity within current measures and metrics will be valuable. Finally, further work is needed to understand better the intricacies of how food insecurity affects FV intake and the experiences of those affected, e.g. the effect of the stress of introducing coping strategies on food choice.

Conclusions

This 1 d member-led meeting focusing on plant-rich DP has provided an update on the latest epidemiological evidence linking such DP to health outcomes across the life course, including in children and older adults, but has also highlighted that plant-rich DP can vary in diet quality and that there is great heterogeneity in such DP. There is also variety in how individuals respond to such DP which is, as yet, relatively unexplored, and efforts to understand such variety in terms of response to FV and mechanisms by which these foods and DP impact health outcomes are underway. We need to be able to measure intake of these foods accurately to allow robust demonstration of association with health outcomes, adherence during dietary interventions and to test the impact of policy changes, and biomarkers are likely to aid this. The issues with observational studies exploring links between plant-rich DP and health outcomes were acknowledged, and the importance of a range of study designs including dietary interventions to allow a strong evidence base to be developed was suggested. The potential impact of such DP on environmental outcomes was presented, with discussion about public awareness of the need for dietary change, the drive for new products to support plant-based diets and need for further research to understand the implications of these new plant-based alternatives in terms of nutritional intake, health outcomes and environmental outcomes clear. The impact of any dietary change on food production systems in their broadest sense (including cultural and economic considerations) was also explored, and the need to consider modern production methods and how these impact on nutritional status and diet quality considered. Across all of these fast-moving changes in diets, a consideration of inequities in access to food must be front of mind, be that physical, social or economic.

Acknowledgements

The organising committee acknowledges the Nutrition Society for the opportunity to host this member-led meeting, and for providing organisational support.

Financial Support

The Nutrition Society provided financial support for the meeting. The local organisers (JW, LB and QS) are co-investigators on a US-Ireland Tripartite Programme sponsored by the US NIH/NIDDK (DK120870). LB was supported by the Health Research Board (USIRL-2019-1). JW was supported by the HSC R&D Division, Public Health Agency and the Medical Research Council (STL/5461/2018). The local organisers acknowledge this financial support of the network of investigators which led to the development of this member-led meeting. QS was supported also by US NIH grants, DK126698 and HL035464.

Conflict of Interest

None.

Authorship

The authors had sole responsibility for all aspects of preparation of the present paper. The authors alone are responsible for the views expressed in this article and they do not necessarily represent the views, decisions or policies of the institutions with which they are affiliated.

References

1. Whitmee S, Haines A, Beyrer C *et al.* (2015) Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation-Lancet Commission on Planetary Health. *Lancet* **386**, 1973–2028.
2. Cornelis MC & Hu FB (2013) Systems epidemiology: a new direction in nutrition and metabolic disease research. *Curr Nutr Rep* **2**, 225–235.
3. Wang DD & Hu FB (2018) Precision nutrition for prevention and management of type 2 diabetes. *Lancet Diabetes Endocrinol* **6**, 416–426.
4. Possemiers S, Bolca S, Eeckhaut E *et al.* (2007) Metabolism of isoflavones, lignans and prenylflavonoids by intestinal bacteria: producer phenotyping and relation with intestinal community. *FEMS Microbiol Ecol* **61**, 372–383.
5. Li J, Li Y, Ivey KL *et al.* (2022) Interplay between diet and gut microbiome, and circulating concentrations of trimethylamine *N*-oxide: findings from a longitudinal cohort of US men. *Gut* **71**, 724–733.
6. Rowland IR, Wiseman H, Sanders TA *et al.* (2000) Interindividual variation in metabolism of soy isoflavones and lignans: influence of habitual diet on equol production by the gut microflora. *Nutr Cancer* **36**, 27–32.
7. Kuijsten A, Arts IC, van't Veer P *et al.* (2005) The relative bioavailability of enterolignans in humans is enhanced by milling and crushing of flaxseed. *J Nutr* **135**, 2812–2816.
8. Li Y, Wang DD, Satija A *et al.* (2021) Plant-based diet index and metabolic risk in men: exploring the role of the gut microbiome. *J Nutr* **151**, 2780–2789.
9. Visser E, Geleijnse JM, de Roos B (2020) inter-individual variation in cancer and cardiometabolic health outcomes in response to coffee consumption: a critical review. *Mol Nutr Food Res* **64**, e1900479.
10. Hazim S, Curtis PJ, Schar MY *et al.* (2016) Acute benefits of the microbial-derived isoflavone metabolite equol on arterial stiffness in men prospectively recruited according to equol producer phenotype: a double-blind randomized controlled trial. *Am J Clin Nutr* **103**, 694–702.
11. National Diet and Nutrition Survey. https://wdwwmrc-epidcamacuk/blog/2020/12/11/ndns-years-9-to-11/ (accessed March 2022).
12. Celis-Morales C, Livingstone KM, Marsaux CF *et al.* (2017) Effect of personalized nutrition on health-related behaviour change: evidence from the Food4Me European randomized controlled trial. *Int J Epidemiol* **46**, 578–588.
13. Sri Harsha PSC, Wahab RA, Garcia-Aloy M *et al.* (2018) Biomarkers of legume intake in human intervention and observational studies: a systematic review. *Genes Nutr* **13**, 25.
14. Brouwer-Brolsma EM, Brandl B, Buso MEC *et al.* (2020) Food intake biomarkers for green leafy vegetables, bulb vegetables, and stem vegetables: a review. *Genes Nutr* **15**, 7.
15. Gibbons H, Michielsen CJR, Rundle M *et al.* (2017) Demonstration of the utility of biomarkers for dietary intake assessment; proline betaine as an example. *Mol Nutr Food Res* **61**. doi: 10.1002/mnfr.201700037.
16. D'Angelo S, Gormley IC, McNulty BA *et al.* (2019) Combining biomarker and food intake data: calibration equations for citrus intake. *Am J Clin Nutr* **110**, 977–983.
17. https://adiet.shinyapps.io/Bio-Intake/ (accessed March 2022).
18. McNamara AE, Walton J, Flynn A *et al.* (2020) The potential of multi-biomarker panels in nutrition research: total fruit intake as an example. *Front Nutr* **7**, 577720.
19. D'Angelo S, Gormley IC, McNamara AE *et al.* (2021) MultiMarker: software for modelling and prediction of continuous food intake using multiple biomarkers measurements. *BMC Bioinf* **22**, 469.
20. Prendiville O, Walton J, Flynn A *et al.* (2021) Classifying individuals into a dietary pattern based on metabolomic data. *Mol Nutr Food Res* **65**, e2001183.
21. Wang DD, Li Y, Bhupathiraju SN *et al.* (2021) Fruit and vegetable intake and mortality: results from 2 prospective cohort studies of US men and women and a meta-analysis of 26 cohort studies. *Circulation* **143**, 1642–1654.
22. Lichtenstein AH, Petersen K, Barger K *et al.* (2021) Perspective: design and conduct of human nutrition randomized controlled trials. *Adv Nutr* **12**, 4–20.
23. Noad RL, Rooney C, McCall D *et al.* (2016) Beneficial effect of a polyphenol-rich diet on cardiovascular risk: a randomised control trial. *Heart* **102**, 1371–1379.
24. Neville CE, Young IS, Gilchrist SE *et al.* (2014) Effect of increased fruit and vegetable consumption on bone turnover in older adults: a randomised controlled trial. *Osteoporos Int* **25**, 223–233.
25. McCall DO, McGartland CP, McKinley MC *et al.* (2011) The effect of increased dietary fruit and vegetable consumption on endothelial activation, inflammation and oxidative stress in hypertensive volunteers. *Nutr Metab Cardiovasc Dis* **21**, 658–664.

26. Gibson A, Edgar JD, Neville CE *et al.* (2012) Effect of fruit and vegetable consumption on immune function in older people: a randomized controlled trial. *Am J Clin Nutr* **96**, 1429–1436.
27. Baldrick FR, Elborn JS, Woodside JV *et al.* (2012) Effect of fruit and vegetable intake on oxidative stress and inflammation in COPD: a randomised controlled trial. *Eur Respir J* **39**, 1377–1384.
28. Wallace IR, McEvoy CT, Hunter SJ *et al.* (2013) Dose–response effect of fruit and vegetables on insulin resistance in people at high risk of cardiovascular disease: a randomized controlled trial. *Diabetes Care* **36**, 3888–3896.
29. Bhupathiraju SN, Wedick NM, Pan A *et al.* (2013) Quantity and variety in fruit and vegetable intake and risk of coronary heart disease. *Am J Clin Nutr* **98**, 1514–1523.
30. Muraki I, Imamura F, Manson JE *et al.* (2013) Fruit consumption and risk of type 2 diabetes: results from three prospective longitudinal cohort studies. *Br Med J* **347**, f5001.
31. Wang T, Heianza Y, Sun D *et al.* (2019) Improving fruit and vegetable intake attenuates the genetic association with long-term weight gain. *Am J Clin Nutr* **110**, 759–768.
32. Bertoia ML, Mukamal KJ, Cahill LE *et al.* (2015) Changes in intake of fruits and vegetables and weight change in United States men and women followed for up to 24 years: analysis from three prospective cohort studies. *PLoS Med* **12**, e1001878.
33. Curtis PJ, van der Velpen V, Berends L *et al.* (2019) Blueberries improve biomarkers of cardiometabolic function in participants with metabolic syndrome-results from a 6-month, double-blind, randomized controlled trial. *Am J Clin Nutr* **109**, 1535–1545.
34. Zong G, Gao A, Hu FB *et al.* (2016) Whole grain intake and mortality from all causes, cardiovascular disease, and cancer: a meta-analysis of prospective cohort studies. *Circulation* **133**, 2370–2380.
35. Aune D, Keum N, Giovannucci E *et al.* (2016) Nut consumption and risk of cardiovascular disease, total cancer, all-cause and cause-specific mortality: a systematic review and dose–response meta-analysis of prospective studies. *BMC Med* **14**, 207.
36. Satija A, Bhupathiraju SN, Rimm EB *et al.* (2016) Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies. *PLoS Med* **13**, e1002039.
37. Satija A, Bhupathiraju SN, Spiegelman D *et al.* (2017) Healthful and unhealthful plant-based diets and the risk of coronary heart disease in U. S. adults. *J Am Coll Cardiol* **70**, 411–422.
38. Li J, Lee DH, Hu J *et al.* (2020) Dietary inflammatory potential and risk of cardiovascular disease among men and women in the U.S. *J Am Coll Cardiol* **76**, 2181–2193.
39. Gardner CD, Hartle JC, Garrett RD *et al.* (2019) Maximizing the intersection of human health and the health of the environment with regard to the amount and type of protein produced and consumed in the United States. *Nutr Rev* **77**, 197–215.
40. Sobiecki JG, Appleby PN, Bradbury KE *et al.* (2016) High compliance with dietary recommendations in a cohort of meat eaters, fish eaters, vegetarians, and vegans: results from the European prospective investigation into cancer and nutrition-oxford study. *Nutr Res* **36**, 464–477.
41. Elliott P, Stamler J, Dyer AR *et al.* (2006) Association between protein intake and blood pressure: the INTERMAP study. *Arch Intern Med* **166**, 79–87.
42. Preis SR, Stampfer MJ, Spiegelman D *et al.* (2010) Dietary protein and risk of ischemic heart disease in middle-aged men. *Am J Clin Nutr* **92**, 1265–1272.
43. Li SS, Blanco Mejia S, Lytvyn L *et al.* (2017) Effect of plant protein on blood lipids: a systematic review and meta-analysis of randomized controlled trials. *J Am Heart Assoc* **6**, e006659.
44. Guasch-Ferre M, Satija A, Blondin SA *et al.* (2019) Meta-analysis of randomized controlled trials of red meat consumption in comparison with various comparison diets on cardiovascular risk factors. *Circulation* **139**, 1828–1845.
45. Chiavaroli L, Nishi SK, Khan TA *et al.* (2018) Portfolio dietary pattern and cardiovascular disease: a systematic review and meta-analysis of controlled trials. *Prog Cardiovasc Dis* **61**, 43–53.
46. Song M, Fung TT, Hu FB *et al.* (2016) Association of animal and plant protein intake with all-cause and cause-specific mortality. *JAMA Intern Med* **176**, 1453–1463.
47. Malik VS, Li Y, Tobias DK *et al.* (2016) Dietary protein intake and risk of type 2 diabetes in US men and women. *Am J Epidemiol* **183**, 715–728.
48. Ma L, Liu G, Ding M *et al.* (2020) Isoflavone intake and the risk of coronary heart disease in US men and women: results from 3 prospective cohort studies. *Circulation* **141**, 1127–1137.
49. Pan A, Sun Q, Bernstein AM *et al.* (2012) Red meat consumption and mortality: results from 2 prospective cohort studies. *Arch Intern Med* **172**, 555–563.
50. Lepine G, Fouillet H, Remond D *et al.* (2021) A scoping review: metabolomics signatures associated with animal and plant protein intake and their potential relation with cardiometabolic risk. *Adv Nutr* **12**, 2112–2131.
51. Qi Q, Li J, Yu B *et al.* (2021) Host and gut microbial tryptophan metabolism and type 2 diabetes: an integrative analysis of host genetics, diet, gut microbiome and circulating metabolites in cohort studies. *Gut* **71**, 1095–1105.
52. Hu FB, Otis BO & McCarthy G (2019) Can plant-based meat alternatives be part of a healthy and sustainable diet? *JAMA* **322**, 1547–1548.
53. Crimarco A, Springfield S, Petlura C, *et al.* (2020) A randomized crossover trial on the effect of plant-based compared with animal-based meat on trimethylamine-*N*-oxide and cardiovascular disease risk factors in generally healthy adults: study with appetizing plant food-meat eating alternative trial (SWAP-MEAT). *Am J Clin Nutr* **112**, 1188–1199.
54. https://sdgs.un.org/goals (accessed March 2022).
55. https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/activities/who-european-childhood-obesity-surveillance-initiative-cosi (accessed March 2022).
56. Fismen AS, Buoncristiano M, Williams J *et al.* (2021) Socioeconomic differences in food habits among 6- to 9-year-old children from 23 countries-WHO European childhood obesity surveillance initiative (COSI 2015/2017). *Obes Rev* **22**(Suppl. 6), e13211.
57. Heinen MM, Bel-Serrat S, Kelleher CC *et al.* (2021) Urban and rural differences in frequency of fruit, vegetable, and soft drink consumption among 6–9-year-old children from 19 countries from the WHO European region. *Obes Rev* **22**(Suppl. 6), e13207.
58. https://www.euro.who.int/en/health-topics/Life-stages/child-and-adolescent-health/health-behaviour-in-school-aged-children-hbsc/about-hbsc (accessed March 2022).
59. Diet Affdaipfpaspfah https://www.who.int/publications/i/item/9789240018341 (accessed March 2022).

60. Ahrens W & Branca F (2021) From data to action: combatting childhood obesity in Europe and beyond. *Obes Rev* **22**(Suppl. 6), e13302.
61. Bakaloudi DR, Halloran A, Rippin HL *et al.* (2021) Intake and adequacy of the vegan diet. A systematic review of the evidence. *Clin Nutr* **40**, 3503–3521.
62. McEvoy CT, Guyer H, Langa KM *et al.* (2017) Neuroprotective diets are associated with better cognitive function: the health and retirement study. *J Am Geriatr Soc* **65**, 1857–1862.
63. Loughrey DG, Lavecchia S, Brennan S *et al.* (2017) The impact of the Mediterranean diet on the cognitive functioning of healthy older adults: a systematic review and meta-analysis. *Adv Nutr* **8**, 571–586.
64. Liu YH, Gao X, Na M *et al.* (2020) Dietary pattern, diet quality, and dementia: a systematic review and meta-analysis of prospective cohort studies. *J Alzheimers Dis* **78**, 151–168.
65. McEvoy CT, Hoang T, Sidney S *et al.* (2019) Dietary patterns during adulthood and cognitive performance in midlife: the CARDIA study. *Neurology* **92**, e1589–e1599.
66. Valls-Pedret C, Sala-Vila A, Serra-Mir M *et al.* (2015) Mediterranean diet and age-related cognitive decline: a randomized clinical trial. *JAMA Intern Med* **175**, 1094–1103.
67. Luciano M, Corley J, Cox SR *et al.* (2017) Mediterranean-type diet and brain structural change from 73 to 76 years in a Scottish cohort. *Neurology* **88**, 449–455.
68. Rainey-Smith SR, Gu Y, Gardener SL *et al.* (2018) Mediterranean diet adherence and rate of cerebral Abeta-amyloid accumulation: data from the Australian imaging, biomarkers and lifestyle study of ageing. *Transl Psychiatry* **8**, 238.
69. Berti V, Walters M, Sterling J *et al.* (2018) Mediterranean diet and 3-year Alzheimer brain biomarker changes in middle-aged adults. *Neurology* **90**, e1789–e1798.
70. Ngandu T, Lehtisalo J, Solomon A *et al.* (2015) A 2 year multidomain intervention of diet, exercise, cognitive training, and vascular risk monitoring versus control to prevent cognitive decline in at-risk elderly people (FINGER): a randomised controlled trial. *Lancet* **385**, 2255–2263.
71. Kulmala J, Ngandu T, Havulinna S *et al.* (2019) The effect of multidomain lifestyle intervention on daily functioning in older people. *J Am Geriatr Soc* **67**, 1138–1144.
72. Strandberg TE, Levälahti E, Ngandu T *et al.* (2017) Health-related quality of life in a multidomain intervention trial to prevent cognitive decline (FINGER). *Eur Geriatr Med* **8**, 164–167.
73. Collaborators GBDRF (2020) Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. *Lancet* **396**, 1223–1249.
74. Schulze MB, Martinez-Gonzalez MA, Fung TT *et al.* (2018) Food based dietary patterns and chronic disease prevention. *Br Med J* **361**, k2396.
75. Gao M, Jebb SA, Aveyard P *et al.* (2021) Associations between dietary patterns and the incidence of total and fatal cardiovascular disease and all-cause mortality in 116,806 individuals from the UK Biobank: a prospective cohort study. *BMC Med* **19**, 83.
76. Kebbe M, Gao M, Perez-Cornago A *et al.* (2021) Adherence to international dietary recommendations in association with all-cause mortality and fatal and non-fatal cardiovascular disease risk: a prospective analysis of UK Biobank participants. *BMC Med* **19**, 134.
77. Report GN https://globalnutritionreport.org/ (accessed March 2022).
78. Clarys P, Deliens T, Huybrechts I *et al.* (2014) Comparison of nutritional quality of the vegan, vegetarian, semi-vegetarian, pesco-vegetarian and omnivorous diet. *Nutrients* **6**, 1318–1332.
79. Fresan U & Sabate J (2019) Vegetarian diets: planetary health and its alignment with human health. *Adv Nutr* **10**, S380–S388.
80. Lelieveld J, Evans JS, Fnais M *et al.* (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* **525**, 367–371.
81. Springmann M, Wiebe K, Mason-D'Croz D *et al.* (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet Health* **2**, e451–e461.
82. Willett W, Rockstrom J, Loken B *et al.* (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet* **393**, 447–492.
83. Scheelbeek PF, Moss C, Kastner T *et al.* (2020) UK's fruit and vegetable supply increasingly dependent on imports from climate vulnerable producing countries. *Nat Food* **1**, 705–712.
84. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/854257/ (accessed March 2022).
85. Anonymous (2021) The beef with beef: treating beef like coal would make a big dent in greenhouse-gas emissions. In *The Economist*. https://www.economist.com/graphic-detail/2021/10/02/treating-beef-like-coal-would-make-a-big-dent-in-greenhouse-gas-emissions (accessed March 2022)
86. Trieu K, Bhat S, Dai Z *et al.* (2021) Biomarkers of dairy fat intake, incident cardiovascular disease, and all-cause mortality: a cohort study, systematic review, and meta-analysis. *PLoS Med* **18**, e1003763.
87. https://www.nutrition.org.uk/news/2020/majority-unlikely-to-go-plant-based-in-the-new-year-bnf-survey-reveals/. (accessed March 2022).
88. Delgado C, Rosegrant M, Steinfeld H *et al.* (1999) *Livestock to 2020: The Next Food Revolution*. India: International Food Policy Research Institute. Sage Publishing.
89. Dixon J (2003) *The Changing Chicken: Chooks, Cooks and Culinary Culture*. Australia: NewSouth Publishing.
90. Steenson S & Buttriss JL (2021) Healthier and more sustainable diets: what changes are needed in high-income countries? *Nutr Bull* **46**, 279–309.
91. Nothing left in the cupboards: Austerity, welfare cuts, and the right to food in the UK. https://www.hrw.org/sites/default/files/report_pdf/uk0519_web4.pdf.
92. Pensions DFWA (2021) Household Food Security data from the Family Resources Survey: financial year 2019 to 2020.
93. (2019) Food insecurity in UK is among worst in Europe, especially for children, says committee. *Br Med J* **364**, l126.
94. S B (2021) Health inequalities: research and policy. https://post.parliament.uk/health-inequalities-research-and-policy/ (accessed March 2022).
95. Aborisade B & Bach C (2014) Assessing the pillars of sustainable food security. *Eur Int J Sci Technol* **3**, 117–125.
96. Nations FaAOotU (1998) *Guidelines for National Food Insecurity and Vulnerability Information and Mapping Systems (FIVIMS): Background and Principles*. Food and Agriculture Organisation.
97. USDA (2021) Definitions of food security. https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-u-s/definitions-of-food-security/.
98. (1990) Core indicators of nutritional state for difficult-to-sample populations. *J Nutr* **120** (Suppl. 11), 1559–1600.

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https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press

99. Pollard CM & Booth S (2019) Food insecurity and hunger in rich countries – it is time for action against inequality. *Int J Environ Res Public Health* **16**, 1804.
100. Committee HoCEA (2019) *Sustainable Development Goals in the UK Follow up: Hunger, Malnutrition and Food Insecurity in the UK*. London: UK Government.
101. Loopstra R (2018) Interventions to address household food insecurity in high-income countries. *Proc Nutr Soc* **77**, 270–281.
102. FAO (2016) *Voices of the Hungry – Measuring food insecurity through people's experiences*. https://www.fao.org/in-action/voices-of-the-hungry/en/ (accessed March 2022)
103. USDA (2012) *U.S. Adult Food Security Survey Module: Three-Stage Design, with Screeners*. Washington, DC: Economic Research Service (USDA).
104. Pensions DfWa (2021) *Family Resources Survey*. https://www.gov.uk/government/collections/family-resources-survey--2 (accessed March 2022)
105. Scottish Government (2021) *Scottish Health Survey*. https://www.gov.scot/collections/scottish-health-survey/ (accessed March 2022)
106. Agency FS (2022) Food and You 2. https://www.food.gov.uk/research/food-and-you-2 (accessed March 2022).
107. FAO (2021) The State of Food Security and Nutrition in the World 2021. https://www.fao.org/documents/card/en/c/cb4474en/ (accessed March 2022).
108. Armstrong B, King L, Clifford R *et al*. (2021) Food and You 2 – Wave 2. https://www.food.gov.uk/research/food-and-you-2/food-and-you-2-wave-2.
109. Pensions DfWa (2021) Family Resources Survey: financial year 2019 to 2020. https://www.gov.uk/government/statistics/family-resources-survey-financial-year-2019-to-2020/family-resources-survey-financial-year-2019-to-2020#household-food-security-1 (accessed March 2022).
110. Smith MD, Rabbitt M & Coleman-Jensen A (2017) Who are the world's food insecure? New evidence from the food and agriculture organization's food insecurity experience scale. *World Dev* **93**, 402–412.
111. Power M, Uphoff EP, Stewart-Knox B *et al*. (2018) Food insecurity and socio-demographic characteristics in two UK ethnic groups: an analysis of women in the born in Bradford cohort. *J Public Health* **40**, 32–40.
112. Leung CW, Epel ES, Ritchie LD *et al*. (2014) Food insecurity is inversely associated with diet quality of lower-income adults. *J Acad Nutr Diet* **114**, 1943–1953, e1942.
113. Spees CK, Clark JE, Hooker NH *et al*. (2017) Dietary intake contributions of food and beverages by source and food security status in US adults. *J Nutr Educ Behav* **49**, 667–673, e661.
114. Hutchinson J & Tarasuk V (2021) The relationship between diet quality and the severity of household food insecurity in Canada. *Public Health Nutr* **25**, 1013–1026.
115. Hanson KL & Connor LM (2014) Food insecurity and dietary quality in US adults and children: a systematic review. *Am J Clin Nutr* **100**, 684–692.
116. Johnson CM, Sharkey JR, Lackey MJ *et al*. (2018) Relationship of food insecurity to women's dietary outcomes: a systematic review. *Nutr Rev* **76**, 910–928.
117. Shi Y, Davies A & Allman-Farinelli M (2021) The association between food insecurity and dietary outcomes in university students: a systematic review. *J Acad Nutr Diet* **121**, 2475–2500, e2471.
118. Turnbull O, Homer M, Ensaff H (2021) Food insecurity: its prevalence and relationship to fruit and vegetable consumption. *J Hum Nutr Diet* **34**, 849–857.
119. Yau A, White M, Hammond D *et al*. (2020) Socio-demographic characteristics, diet and health among food insecure UK adults: cross-sectional analysis of the international food policy study. *Public Health Nutr* **23**, 2602–2614.
120. Yang TC, Sahota P, Pickett KE *et al*. (2018) Association of food security status with overweight and dietary intake: exploration of White British and Pakistani-origin families in the Born in Bradford cohort. *Nutr J* **17**, 48.
121. EATSF (2021) Vouchers 4 Veggies Eat SF: Impact Report. http://eatsfvoucher.org/wp-content/uploads/2021/08/impact-report_final-1-1.pdf (accessed March 2022).
122. Haines BC, McKay FH, Dunn M *et al*. (2018) The role of social enterprise in food insecurity among asylum seekers. *Health Soc Care Community* **26**, 829–838.

https://doi.org/10.1017/S002966512200266X Published online by Cambridge University Press