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Is There a Specific Role for Fungal Protein Within Food Based Dietary Guidelines? A Roundtable Discussion

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ABSTRACT

Expanding and aging populations, sustainability drivers and changing attitudes to the way we eat mean that there has been growing interest in non-animal derived protein food sources. Given this shift, there has been an uprise in consumer demand and commercial innovation of meat analogues and alternative protein food sources. The question, with a focus on fungal proteins, is where to best place them within Food-based Dietary Guidelines? A Nutrition Society Member-Led meeting was convened as a roundtable on 12th February 2024 to gather views on whether there is a specific role for fungal protein within Food-based Dietary Guidelines and how this role is best communicated. The intention of the roundtable was to establish areas of consensus or any disparities, and pinpoint future research directions. The roundtable format included three contextual presentations followed by discussions around seven core statements. A group of 11 experts from academia, policymaking and industry participated. There was agreement that health and sustainability research had advanced (for mycoprotein in particular). Subsequently, there is no reason to exclude fungal-derived proteins from Food-based Dietary Guidelines. The panel agreed on the need for an updated database on mycoprotein intakes in different countries along with long-term population studies comparing fungal, plant and meat sources against health and sustainability outcomes. The consensus was that fungal-derived mycoprotein could be represented within Food-based Dietary Guidelines, within a 'non-animal/non-meat' or 'other protein' sector, or as part of a generic protein diversification message.

1 | Introduction

The global population is anticipated to exceed 10 billion by the year 2050, placing a heavy strain on the resources needed to meet per capita animal-derived protein consumption, which has been rising (Aimutis 2022). This is largely being fuelled by growing and aging populations placing demands on global needs for animal protein (Smith et al. 2024). It has been estimated that around 400 million tons per annum of protein-containing foods will be needed by 2050, which will need to come from a range of sources (Daniel 2024).

An inability to sustainably and ethically meet demands for animal protein, alongside consumer trends of reducing their meat consumption and rising supply of novel protein alternatives, has given rise to a "protein shift" (Yano and Fu 2022). There is a lack of a consistent definition when it comes to sustainability although the three E's of environment, equity and economics can help to provide some clarification (Brinkmann 2023). The United Nations Brundtland Commission defined sustainability in 1987 as '*meeting the needs of the present without compromising the ability of future generations to meet their own needs*', a definition that is used today by the United Nations (UN 2025; UNBC 1987). Consequently, 'plant-based' foods have become popular as a pathway to promote animal welfare, human health and lower environmental footprints of diets (Alcorta et al. 2021). Fungi are increasingly being viewed as an important source of edible proteins but are yet to have a well-defined presence in Food-based Dietary Guidelines (FBDG) (Derbyshire et al. 2023; Wang et al. 2023). Given that shifts in eating habits are now contributing to the concept of 'protein diversification' (Colgrave et al. 2021) there is scope to consider whether fungi and products derived from fungal proteins should have a more prominent role as part of this shift.

In view of interest surrounding this topic, a Member-Led Meeting was held on February 12th, 2024, at the Nutrition Society headquarters in London, as a roundtable event. The main objective was to gather views on fungal proteins and where they might best sit within FBDG, identifying any areas of (or lack of) consensus.

Regarding the approach, a diverse group of 11 experts, three of whom undertook presentations, and two observers were assembled to bring different perspectives to the roundtable discussion. This included representatives from academia, policymaking, and industry (see acknowledgements section). Participants had backgrounds in exercise physiology, health and lifespan nutrition, sustainability, sensory science/eating behaviour and mycology. Key reports and peer-reviewed scientific publications were provided as pre-reading prior to the discussion meeting (Humpenoder et al. 2022; Lockyer et al. 2023; Farsi et al. 2022; Holt et al. 2024; Finnigan et al. 2024). Seven core discussion statements were also circulated by organisers before the event in advance of discussions. This approach was based on the view that panel discussions with group leaders can facilitate conversation, ignite debate and introduce further thinking about a topic (Iyer et al. 2024).

Regarding outputs, the roundtable was chaired by Professor John Brameld (School of Biosciences, University of Nottingham). To set the scene, three contextual presentations were given. These presentations were followed by group discussions, which followed a structured approach. The seven position statements that had been provided by the organisers prior to the meeting were discussed in sequence. The Chair presented the statements and regulated the discussion. The roundtable sponsors were not present in the roundtable meeting. This report first provides an overview of the three expert presentations followed by points raised and generated from the discussion questions.

2 | Fungi as Food: Land Use, Sustainability and Carbon Emissions

2.1 | Land Use Conflict

Professor Paul Thomas discussed the topic of fungi as food, focusing on land use and carbon emissions. He explained how in 2017 the Food and Agriculture Organisation of the United Nations projected that a 50% increase in global food production (compared to baseline figures in 2012) would be needed to meet demands attributed to population growth, changing dietary habits and socioeconomic demographics (FAO 2020). These predictions are reinforced by a meta-analysis of 57 global food security projection scenarios, concluding that total global food demand is estimated to rise by 35%–56% between 2010 and 2050 (Van Dijk et al. 2021). This demand creates land use conflict and results in deforestation to make way for agricultural food production. Even with reforestation activities, demand for agricultural land is a key driver in the net annual loss of 4.7 million hectares of forest (FAO 2020). Forests provide irreplaceable ecosystem services, housing biodiversity and crop pollinators whilst fuelling carbon sequestration and water cycling (Ellwanger et al. 2020; Dall'agnol et al. 2022).

This creates a cyclical 'wicked problem' (Figure 1) (Thomas and Jump 2023). Extreme weather events, disrupted water cycles, desertification and weather uncertainty reduce agricultural output, meaning more land is needed to maintain production. These issues result in further deforestation, land use conflict and greater greenhouse gas emissions and accelerates climate change. Subsequently there are projected to be considerable global and regional temperature rises, with Asia and Africa expected to experience a temperature increase of more than 1.6°C (Ahmed et al. 2023).

2.2 | Fungi and Sustainability

Professor Thomas explained that fungi have been gaining interest globally due to their broad roles in food systems and health (Niego et al. 2021). There are four main categories of fungi: (1) Cultivated, (2) Wild harvest, (3) Microbial production

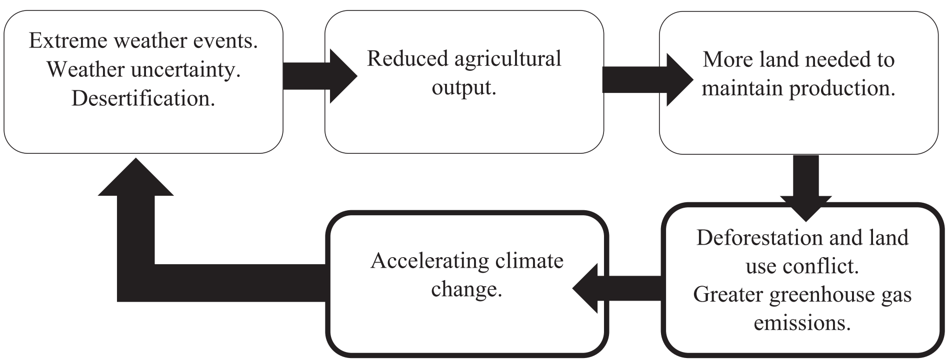

FIGURE 1 | Land Use Conflict Cycle. *Source:* Adapted from Thomas and Jump (2023) (Thomas and Jump 2023).

and (4) Ectomycorrhizal fungi mycoforestry (plant symbionts cultivated with their host plants, in a system that looks like commercial forestry). China is one of the largest producers of mushrooms—their cultivation ranks within the top five after grain, vegetable, fruit and edible oil plantation and is more profitable (Li and Xu 2022; MI 2024; Cahanovitc et al. 2022). Other models show that substituting 20% of per capita ruminant meat consumption with microbial protein globally (on a protein basis) attenuates projected increases in annual deforestation and related carbon emissions by around half when estimated up to 2050 (Humpenoder et al. 2022).

3 | Role of Fungi Proteins in Muscle Anabolism, Cardio-Metabolic Health and the Microbiome

Professor Benjamin Wall presented research on mycoprotein consumption and muscle anabolism, cardio-metabolic health, and the microbiome. While some non-animal proteins possess favourable environmental credentials, less is known about their effects on muscle anabolism (Van Der Heijden et al. 2023). Mycoprotein is viewed as a protein- and fibre-rich whole-food source providing around 45 g protein and 25 g fibre per 100 g mycoprotein (dry weight) (Coelho et al. 2020). He explained how it is important to quantify and express units of measurement when discussing protein and protein quality (Van Der Heijden et al. 2023). Plant-based proteins tend to have lower levels of key signalling amino acids such as leucine and other essential amino acids such as methionine or lysine (Berrazaga et al. 2019; WHO 2002). Plant-derived proteins can also contain anti-nutritional factors that inhibit digestion, thereby reducing the digestibility and absorption of various nutrients, including amino acids (Petroski and Minich 2020). Fungal biomass (mycoprotein) provides all the essential amino acids (Souza Filho 2022) although it is not particularly high in leucine.

3.1 | Muscle Anabolism

Professor Wall described the evidence in relation to mycoprotein and muscle anabolism. Dunlop et al. (2017) fed similar boluses of animal and fungal-based proteins in experimental trials with 12 healthy young men and measured amino acid availability in the circulation, showing comparable blood levels in the postprandial period, although the digestion and absorption of mycoprotein were relatively slow (Dunlop et al. 2017). This could be attributed to its unique cellular structure. Monteyne et al. (2020b) undertook a double-blind, randomised, parallel-group study with 19 young men and studied muscle anabolism using isotopically labelled amino acids to quantify muscle protein synthesis (MPS) in response to mycoprotein or milk protein ingestion (Monteyne et al. 2020b). Unexpectedly, there were higher muscle protein synthetic responses to mycoprotein compared to milk protein ingestion. In general, mycoprotein appears to be a bioavailable source of amino acids that could have potential synergistic effects on muscle mass (West et al. 2023c, 2023a; Monteyne et al. 2020a, 2020b). In later studies, MPS rates have been quantified over several days rather than after a single meal. Mycoprotein consumption across several days results in similar MPS rates as omnivorous diets in both younger and older individuals (Monteyne et al. 2023, 2021).

Research on mycoprotein and other alternative protein sources is now gaining pace in sports science and policy settings, particularly in the context of sports nutrition, active aging and muscle mass maintenance (West et al. 2023b; Van Der Heijden et al. 2023). Increased interest in sustainability is also driving conversations about protein food sources within sports settings (Lynch et al. 2018).

3.2 | Cardiometabolic Health

Professor Wall described the evidence-base for effects of mycoprotein on cardiometabolic health. Three key studies conducted in the 1980s and 90s focused on the cholesterol lowering effects of mycoprotein consumption (Udall et al. 1984; Turnbull et al. 1990, 1992). For example, a randomised controlled trial (RCT) undertaken by Udall et al. (1984) found that mycoprotein (20 g dry weight per day) fed to 100 adults (20–26 years) over 30 days resulted in a 7% reduction in blood cholesterol levels (Udall et al. 1984). Later, Turnbull et al. (1990) recruited adults ($n = 17$, 19–48 years) with hypercholesterolaemia to take part in a RCT and provided 191 g mycoprotein daily (40 g dry weight; Quorn versus meat) for 3 weeks. Diets were energy and macronutrient balanced (except for fibre) and after 3 weeks there was a 13% reduction in total cholesterol, a 9% decrease in low-density lipoprotein cholesterol (LDL-C), and a 12% increase in high-density lipoprotein cholesterol (HDL-C) compared with the control (Turnbull et al. 1990). In 1992, the same team administered 27 g (dry weight) of mycoprotein to staff or students ($n = 21$, 25–61 years) or a control in the form of cookies, which were consumed daily over 8 weeks (Turnbull et al. 1992). Energy and macronutrient profiles of diets were matched, including fibre. There was a 16% reduction in total cholesterol and a 21% reduction in LDL-C, with no change in HDL-C (Turnbull et al. 1992).

These findings have been reproduced in two more recent studies (Coelho et al. 2021; Pavis et al. 2024). Coelho et al. (2021) recruited healthy, recreationally active, young people ($n = 20$) to eat a fully controlled diet where lunch and dinner contained either mycoprotein (181 g Quorn) or meat/fish (control group) as the primary source of dietary protein for 1 week. An analysis of metabolomics showed that total plasma cholesterol, free cholesterol and LDL-cholesterol decreased to a larger degree (14%–19%) in the mycoprotein compared with the control group (3%–11% reduction) (Coelho et al. 2021). Pavis et al. (2024) recruited overweight adults with hypercholesterolaemia and conducted a community-based, controlled, parallel-group study ($n = 72$) during free-living conditions. Participants consumed 160 g wet weight of Quorn products or meat/fish control products daily over 4 weeks and diets were energy and macronutrient matched apart from dietary fibre. There was a 5% reduction in total cholesterol and 10% decline in LDL-cholesterol in the mycoprotein group (Pavis et al. 2024).

Regarding glycaemic health, some studies demonstrated an acute response to mycoprotein ingestion measured using acute glucose tolerance tests (Turnbull and Ward 1995). Research by Turnbull and Ward (1995) provided mycoprotein via milkshake consumption to young adults ($n=19$) which increased the fibre intake (5g fibre in the mycoprotein milkshake versus 1.1g in the control) finding that markers of glycaemia were significantly reduced post meal compared with the control.

Regarding satiation, research by Turnbull et al. (1993) found that acute mycoprotein ingestion in young adults ($n=13$) resulted in greater appetite suppression and reduced *ad libitum* food intake (24% over the remainder of the day, and 17% the following day) compared with isoenergetic and isonitrogenous chicken meals (Turnbull et al. 1993). Similar findings have been reported by other studies (Burley et al. 1993; Williamson et al. 2006; Bottin et al. 2016).

Overall, these studies indicate that mycoprotein consumption could have cholesterol-lowering and glycaemic benefits. Both of these beneficial effects are likely attributable to the fibre content and/or specific fibre type. The community-based intervention indicates that these effects could extend beyond laboratory settings. Larger population studies with larger sample sizes and subgroup analyses (e.g., males and females of different ages) would be informative. Future studies should also consider recording compliance with mycoprotein interventions.

3.3 | Microbiome

Professor Wall described the evidence on the gut microbiome. Alongside being a protein source, the fibre content and fibre profile of mycoprotein are of relevance to gut health (Harris et al. 2019). Previous in vitro work on the colonic fermentation of mycoprotein found changes in *Bacteroides* species known for degrading β-glucans (Colosimo et al. 2024). Other work identified that β-glucans present in mycoprotein are consumed by primary degraders which engage extracellular, endo-acting enzymes to degrade β-glucan, releasing oligosaccharides which are then utilised by secondary degraders (Fernandez-Julia et al. 2023).

In the 'Mycomeat' study, healthy males ($n=20$) were allocated to eat 240g/day of red and processed meat for 2weeks, with crossover to 2weeks of 240g/day mycoprotein, separated by a 4-week washout period (Farsi et al. 2023). Results showed that the red meat diet increased nitroso compound excretion and faecal genotoxicity, whilst mycoprotein consumption reduced these and improved profiles of *Lactobacilli, Roseburia* and *Akkermansia* (Farsi et al. 2023). Although emerging data is interesting, more work is needed to clarify and build on these studies.

4 | Fungi Versus Plants: Taxonomy, Nutritional Value, Role in the Diet and Representation in FBDG

Dr. Emma Derbyshire discussed that protein guidance has tended to be dichotomous, dividing protein sources into animal versus plant, with other categories such as fungal proteins being overlooked (Derbyshire 2022). From a historical perspective, in 1955 George Martin, an American mycologist, was one of the first scientists to question whether fungi were plants (Martin 1955). He believed that they were not, due to fungi lacking chlorophyll for photosynthesis, vascular tissue for water and nutrient transport, and reproducing via spores rather than seeds (Martin 1955) (also refer to Table 1). In 1959 Robert Whittaker, a plant ecologist, published a system representing the central 'Kingdoms of Life'. This was initially a four-kingdom system (Plantae, Fungi, Animalia and Protista) but later evolved into a six-kingdom system once bacteria and ancient bacteria were added (Hagen 2012; Whittaker 1959).

In the present day, heightened interest in fungi from a food perspective has been growing against the backdrop of interest in dietary diversification, sustainable diets and transitions from animal to plant-based protein (Moura et al. 2023; Langyan et al. 2021). Fungi can be consumed in the diet mainly as mushrooms and fungal protein food products for example, Quorn. This interest is reflected in the recent Nordic Nutrition Recommendations which list fungi (in the form of mycoprotein) as a dietary source of non-animal protein (NC 2023).

TABLE 1 | Fungi versus plant taxonomy.

	Fungi	Plants
Has chlorophyll?	Lack chloroplasts and chlorophyll	Have chloroplasts and chlorophyll
Major cell wall component	Chitin and N-acetylglucosamine	Cellulose (glucose)
Food production	Fungi live off others – they cannot produce their own food (heterotrophic)	Plants can produce their own food (autotrophic)
Digest food before uptake?	Yes	No
Form of gametes	Fungi reproduce through spores	Plants reproduce via seeds/pollen
Structural differences	Fungi is filamentous – mycelium and hyphae	Plants have roots, leaves, and stems
Form of food storage	Glycogen	Starch
Trophic level	Decomposers in the ecosystem	Producers in the ecosystem
Molecular level	Fungi are more closely related to animals than plants. They have the last common ancestor	Fungi are not plants. They do not have the last common ancestor

Source: (Martin 1955); (Whittaker 1959); (Carlile et al. 2001); (Feeney et al. 2014b, 2014a); (Naranjo-Ortiz and Gabaldon 2019); (Parliament 2024).

4.1 | Fungi as Food – Past, Present, Future

Dr. Derbyshire explained how the total number of fungal species on the earth could be around 11.7–13.2 million, far exceeding current estimates of 2.2–3.8 million species, given new advancements in sequencing technologies that can identify additional species of fungi (Wu et al. 2019).

In human history, fungi have been used as medicine in early Chinese, Egyptian, Greek, Mexican and Roman civilisations (Feeney et al. 2014b). Some best-known fungal-derived food sources include truffles, tempeh and mycoprotein (Duppont et al. 2017; Thavamani et al. 2020). Miso (a fermented paste) is a central part of the Japanese diet and is derived from grains, soybeans and koji fungi, which provide a umami flavour (Kusumoto et al. 2021). Fungal chemistry also has important roles in the pharmaceutical industry, for example, for statin development (Chester and EL Guindy 2021). Consequently, a large and growing part of the economy depends on fungi.

4.2 | Meta-Analytical Evidence for Fungi and Health

Dr. Derbyshire described the body of evidence relating to fungi, which included mushrooms and mycoprotein, and health. For mushrooms, meta-analytical publications of observational studies have predominantly focused on inter-relationships between mushrooms and lower gastric, breast and lung cancer risk (Woo et al. 2014; Li et al. 2014; Ba et al. 2021, 2023). For mycoprotein, meta-analyses of intervention trials and systematic reviews report potential associations with reduced energy intake and lower measured insulin responses to meals (Cherta-Murillo et al. 2020) and improved blood glucose and lipid profile (Iqbal et al. 2022; Derbyshire and Delange 2021; Shahid et al. 2023). This may be attributed to the fibre component in mycoprotein modifying energy intake and lipid profile (Turnbull et al. 1992, 1993). One-third of the fibre in mycoprotein is typically chitin (poly *N*-acetyl glucosamine) and two-thirds β-glucan (both 1,3-glucan and 1,6-glucan) (Denny 2008). Fermentation of such fibres appears to yield short-chain fatty acids which stimulate the release of the gut peptides, Peptide YY and glucagon-like peptide-1, by activating the free fatty acid 2 and 3 receptors, suggesting that this could be a mechanism underpinning reductions in energy intake (Den Besten et al. 2013; Harris et al. 2019). Mechanisms for these effects remain to be fully elucidated. More trials are now needed to investigate broader aspects of health across a range of life stages, such as childhood and pregnancy.

4.3 | Mycoprotein Focus

Dr. Derbyshire described how in 1967 the United Kingdom food industry was struggling to restart levels of pre-war food production, so Lord Rank, the chair of Rank Hovis McDougall (a producer of cereals), sought to identify an alternative protein source using the starch produced as a byproduct of flour milling (Finnigan et al. 2024). Over 3000 global soil samples were analysed and the organism *Fusarium venenatum* (originally misidentified as *Fusarium graminearum*) was found in a garden in Marlow, Buckinghamshire (Finnigan et al. 2024). This organism is a member of the *Ascomycota* branch of the fungi family and today is used to produce mycoprotein (using vertical air lift fermentation) with Quorn (the brand name of the first producer of foods from mycoprotein) being used interchangeably with mycoprotein in some countries. Such fermentation facilities have been used for many years to produce drugs but are now being adapted globally to produce alternative proteins and support progress in food system sustainability (GFI 2022). As of February 2024, over 38 companies use bulk fermentation of fungi to produce foods, highlighting the growth of this evolving, multiplayer industry (FPA 2024).

The United Kingdom National Diet and Nutrition Survey (NDNS) provides insight into mycoprotein consumption among UK consumers. Analysis of the years 2008/2009–2016/2017 showed that mycoprotein consumers had an average intake of 147 g/d (about 2 servings and 8% of their total energy intake) (Cherta-Murillo and Frost 2022). Mycoprotein consumers (about 3% of the cohort) also had significantly higher dietary fibre intake compared to non-consumers—23.9g versus 18.6 g/day, respectively, although their diet may also have differed in other ways (Cherta-Murillo and Frost 2022).

From a nutritional perspective, mycoprotein is lower in sugars, total fat and saturated fatty acids and higher in fibre, riboflavin, manganese and zinc when compared with other non-animal protein products (LoŽnjak Švarc et al. 2022). Some research has examined the potential nutritional impact of replacing dietary meat with meat alternatives (Farsi et al. 2022). This study used NDNS data and undertook a modelling analysis where meat categories were replaced with closest match supermarket mycoprotein alternatives and found that complete meat substitution with mycoprotein resulted in a 6 g/day daily reduction in total fat and an 8 g/day increase in fibre but also a decrease in protein (9 g/day), iron (1 mg/day) and vitamin B12 (1.5 μg/day) and an increase in sodium (312 mg/day) (Farsi et al. 2022).

4.4 | Time to Update FBDG?

Dr. Derbyshire explained that FBDG formats differ by country and organisation. There are sizeable discrepancies between protein guidance across global FBDG. In a review of FBDG from 90 countries, inconsistencies between protein messages were observed (Herforth et al. 2019). Another review of FBDG from 100 countries concluded that only 40% had a position on vegetarian diets and that FBDG should be revised at least every 5 years (Klapp et al. 2022). James-Martin et al. (2022) assessed national FBDG from 87 countries, finding that only 37 mentioned environmental sustainability, with few indicating why sustainability is important (James-Martin et al. 2022). Springmann et al. (2020) reviewed 85 sets of global FBDG and concluded that 84% were not compatible with at least one of the global health and environmental targets (Springmann et al. 2020) (Table 2).

In the UK, mycoprotein is included as 'other vegetable-based source of protein' in 'The Eatwell Guide' booklet under the category of 'beans, pulses, fish, eggs, meat and other proteins' but is not present in the visual infographic (OHID, Updated 2024). Similarly, in Switzerland, Quorn is included under the category of 'Dairy Products, Meat, Fish, Eggs and Tofu' as 'another

TABLE 2 | Definitions/explanations of FBDG.

Definition/explanation	Source
"FBDG are science-based recommendations for healthy eating which translate numerical nutrition targets into lay advice on what foods to eat"	(EFSA 2025)
"FBDG (also known as dietary guidelines) are intended to establish a basis for public food and nutrition, health and agricultural policies and nutrition education programmes to foster healthy eating habits and lifestyles. They provide advice on foods, food groups and dietary patterns to provide the required nutrients to the general public to promote overall health and prevent chronic diseases"	(FAO2025)
"FBDG are an attempt to translate a vast (and incomplete) evidence base regarding relations between food, diet patterns and health into specific, culturally appropriate, and actionable recommendations"	(Herforth et al. 2019)
"FBDGs are important tools for nutrition policies and public health. They provide guidelines on healthy food consumption and are based on scientific evidence. In the past, disease prevention and nutrient recommendations dominated the process of establishing FBDGs. However, scientific advances and social developments such as changing lifestyles, interest in personalised health, and concerns about sustainability require a reorientation of the creation of FBDGs to include a wider range of aspects of dietary behaviour"	(Bechthold et al. 2018)

protein-rich food' but is not visually represented in the Swiss Food Pyramid (SGE/SSN 2024). The One Blue Dot report published by the UK British Dietetic Association advised that plant proteins such as beans and lentils, soya, mycoprotein, nuts and seeds should be increased to fuel eating patterns for health and environmental sustainability (BDA 2020). In Norway, '*Fungi (in the form of mycoprotein)*' are mentioned as *a source of non-animal protein* in the Nordic Nutrition Recommendations (NC 2023).

5 | Roundtable Discussion–Identifying Areas of Consensus

To initiate discussion, a number of statements were examined by roundtable participants. The statements presented below were formulated to stimulate debate, and therefore should not be treated as facts:

- *Discussion Statement 1*: Fungi are a recognised and established food source, a distinct kingdom, separate from that of plants and animals.
- *Discussion Statement 2*: Fungi-derived proteins are inferior protein foods compared to animal protein.
- *Discission Statement 3*: There is a discernible sustainability case for the inclusion of fungi derived proteins in sustainable healthy diets in support of protein diversification, and it is insufficient to just recognise plants and animals as protein sources.
- *Discussion Statement 4*: There is an increasing body of evidence on the role of fungi-derived proteins and health to warrant their inclusion in healthy, sustainable diets and food-based dietary guidelines.
- *Discussion Statement 5*: Fungi-derived proteins should be better recognised in food-based dietary guidelines around the world to address future protein demands.
- *Discussion Statement 6*: The health science and nutrition data suggest that fungi-derived proteins should not be considered ultra-processed, and classifying them as such would have a detrimental impact/effect on transitions to more sustainable diets.
- *Discussion Statement 7*: Consumers fully understand the role that fungi and fungi-derived proteins play in healthy, sustainable diets. There is no need for raising consumer awareness to change consumption behaviours.

Discussion Statement 1. *Fungi are a recognised and established food source, a distinct kingdom, separate to that of plants and animals*

It was agreed that fungi are a recognised and established food source, with records of consumption going back four thousand years. From a taxonomy perspective, it was viewed that fungi are a separate and distinct kingdom. Nevertheless, we seem to focus on a dichotomy of animal versus plant-based protein in dietary recommendations (Derbyshire 2020). It was questioned whether the emphasis should now move more toward protein diversification. The concept of an animal-derived and non-animal-derived split/grouping system was raised. It was thought that such an approach could help to better capture a range of foods that are not derived from animals and avoid the terminological confusion, although the inclusion of foods such as cultured meat is subject to debate.

Two participants noted that culinary use, as opposed to biological classification, is important to consider when thinking about how best to communicate dietary guidelines. For example, mycoprotein may be viewed as a non-animal derived protein but mushrooms are treated as a vegetable. We also do not solely eat protein, so mycoprotein consumption may be accompanied by other foods such as vegetables and legumes. Another view was that given the rise in alternative proteins, the public need to become aware of how and where these sit within daily diets and a protein diversification message may be more relevant than food groupings. An example of fungi being included in FBDG was shared, in that dietary guidelines for vegetarians in China specify '*eat nuts, seaweed and fungi regularly*' (Yang et al. 2018).

It was discussed how this statement related to 'protein quality' and how mycoprotein and its animal acid profile appears to be more closely related to the profile of animal-derived proteins than plant-based proteins. One participant explained that when we think of FBDG we tend to relate these more specifically to health and the environment, rather than protein quality. The general population of economically advanced regions also tends to eat more than the recommended protein intake and focusing on protein quality per se could lead to unnecessary overconsumption (Box 1).

Discussion Statement 2. Fungal-derived proteins are inferior protein (quality) foods, compared to animal protein.

The term 'inferior' was thought to refer to the nutritional profile of fungal-derived protein foods, although this question could also be viewed from a sustainability stance. Protein quality and digestibility are also important in relation to this statement.

One caveat is that studies have focused on healthy, young individuals in the form of acute feeding studies on muscle metabolism. These have been in rather niche populations such as healthy males, indicating that other population groups would be worthy of study. Longer-term health outcomes are important, and these should be broadened in fungal-derived protein research to include development and growth in childhood and sarcopenia in advanced age. There is a need to look more broadly at fungal-derived protein foods due to their high-fibre content and satiating potential as health effects could be different in longer-term trials. One participant mentioned that a broad-brush approach looking at an array of fungal-derived proteins and implications for longer-term health outcomes would be worthwhile in different populations and stages of life.

Research at present on health effects is predominantly mycoprotein centric, focusing on *Fusarium venenatum*. Other forms of fungi (about 50 species are consumed in the UK) are not as well studied. It was concluded and advised that two distinct statements may be warranted– one in relation to mycoprotein and one for other sources of fungal proteins, such as mushrooms.

The idea that proteins should be viewed in the context of the 'whole diet' was also discussed since individuals are generally exposed to a range of amino acids—although this may not be the case globally. This makes the discussion of inferiority less significant in economically advanced regions (Box 2).

Discussion Statement 3. *There is a discernible sustainability case for the inclusion of fungal derived proteins in sustainable healthy diets in support of protein diversification, and it is insufficient to just recognise plants and animals as protein sources.*

It was generally agreed that fungal-derived proteins could be included within a sustainable healthy diet. Whether they need distinct recognition from plants is less clear. There are some challenges defining plant-based diets, and the field would benefit from some consensus of definitions.

One panellist thought it could be enough to have animal versus non-animal protein sources as food groupings. From an animal welfare stance, consumers tend to want to know whether something is 'non-animal'. It was also discussed how a clear distinction is needed from a health perspective. It was questioned whether such terminology would have appeal in public domains, including where cultured meat would be categorised. This is something that would need to be further investigated.

At present there is not yet widespread use of the 'non-animal protein' terminology. One publication refers to 'non-animal proteins' as sources of protein that qualify for vegan, vegetarian, and flexitarian diets, which could be derived from fungi, bacteria, algae (seaweed and microalgae), pulses, vegetables and cereals (Boukid et al. 2022). Some publications, such as the EPIC-Oxford Cohort refer to 'non-meat eaters' and 'meat eaters' or 'fish eaters' as groupings (Papier et al. 2019). This appears to align with the thinking of the panel when it comes to categorisation (Box 3).

Discussion Statement 4. *There is an increasing body of evidence on the role of fungal-derived proteins and health to warrant their*

BOX 1 | Areas of consensus for Discussion Statement 1.

- Fungi is a recognised and established food source and a distinct Kingdom with a long history of use.
- It was agreed that although biologically fungi are a distinct Kingdom, this is perhaps less important to differentiate in nutrition-related public communication.
- FBDG should continue to focus on health and the environment rather than 'protein quality'.
- Fungi could form part of a 'protein diversification' message or fall within groupings of 'non-animal derived protein'.

BOX 2 | Areas of consensus for Discussion Statement 2.

- Current studies on fungal-derived proteins derived from *F. venenatum* show they are not inferior protein (quality) foods compared to animal protein.
- More research is needed to study other fungal strains and mushrooms before such a statement could be endorsed.
- Past studies looking at MPS have tended to be conducted with healthy, young adults. It would be useful to extend this across other life stages, comparing the effects of different fungal-derived proteins.
- Longer-term studies are needed at critical life stages to investigate the effects of fungal proteins on health outcomes such as growth, development, frailty, and sarcopenia in the aged.

BOX 3 | Areas of consensus for Discussion Statement 3.

- From a protein diversification perspective, it was agreed that we could move toward broader categories of 'non-animal' and 'animal' protein. Or 'non-meat' and 'meat' eaters.
- There was a consensus that differentiation between these two categories could be useful from a health perspective given that different dietary patterns can lead to different health outcomes.
- The general view was that we should focus less on two dichotomous groups by placing greater emphasis on protein diversification.

inclusion in healthy, sustainable diets and food-based dietary guidelines.

The discussion commenced with one participant explaining it would be beneficial to compare fungal-derived proteins with plant-derived proteins across several categories. Equally, the beta-glucan and chitin ratio of mycoprotein is complex. There appear to be unanswered questions and a need for further study on this topic. There is scope to undertake research using other foods with a similar chitin/beta-glucan profile as a comparator. The evidence for mushroom (derived proteins) remains scarce compared to mycoprotein.

Using earlier data from the National Diet and Nutrition Survey between 2008 and 2017, 3% of the adult UK sample population were identified as mycoprotein consumers (Cherta-Murillo and Frost 2022). Of these, 28% were vegetarian, <1% were vegan, and 72% were omnivores (Cherta-Murillo and Frost 2022). However, given dietary shifts in recent years, there is a need for updated figures once the new NDNS data are published. Diet modelling is also needed to better understand the effects of transitioning to non-animal derived food proteins and potential unintended consequences in relation to micronutrient intakes and status. Well-designed prospective cohort studies would be worthwhile to supplement data from RCTs. Other outcomes beyond cardiovascular and muscular health, such as gut health, constipation, and bone health across critical phases of life would all be worthwhile.

Today, in the United Kingdom, some school menus include mycoprotein (Quorn), but there does not seem to be research monitoring intakes in children across the childhood years in relation to developmental outcomes when swapping from animal-derived proteins. Dietary assessment methods may need to be tailored and updated to collate such data. As the NDNS used 4-day food diaries or, more recently, 4-day 24h recalls (OHID 2023), mycoprotein or fungal-derived protein consumption on non-recorded days could be missed. Therefore, the use of an accompanying validated food frequency questionnaire could be useful in helping to fully capture this dietary exposure. It was emphasised that swapping from animal-derived to non-animal-derived proteins may impact micronutrient intake.

BOX 4 | Areas of consensus for Discussion Statement 4.

- There is evidence in limited population groups on the role of fungal-derived protein and health to warrant inclusion in healthy, sustainable diets and FBDG.
- There is no evidence to suggest they should be excluded from FBDG.
- There is a need for more research making direct comparisons between fungal-derived protein and plant-based proteins across the lifecycle, including critical stages of growth.
- When focusing on health, we must consider the impacts of transitioning to non-animal-derived protein sources on micronutrient intakes.
- Use of the term mycoprotein could be considered in FBDG.

The panel further discussed how the fibre profile of non-animal derived proteins needs to be considered due to its inhibitory effects on bioavailability of certain nutrients, such as iron and vitamin B_{12}, which could have ramifications for certain subpopulations, such as expectant mothers or the elderly.

Additionally, in terms of how to visually represent fungal-derived protein within FBDG it was agreed that an impartial image or infographic to be used within FBDG visual representations would be most impactful. It was also mentioned that people relate to Quorn better than fungi or mycoprotein terminologies, therefore this wording could be utilised as an example, or mycoprotein could be considered as a separate entity as they do in Norway which states that "*Fungi (in the form of mycoprotein) are also a source of non-animal protein*" (NC 2023) (Box 4).

Discussion Statement 5. *Fungal-derived proteins should be better recognised in food-based dietary guidelines around the world, to address future protein demands*

Mycoprotein is not yet available/authorised for consumption in some countries globally, for example, in Canada and Poland. As a starting point it was mentioned that some dietary guidelines, such as the Nordic Nutrition Recommendations do include fungal protein (NC 2023). However, this inclusion is in written form rather than visual representation in infographics. Imagery used in FBDG could be expanded to include a wider array of proteins such as mycoprotein, tofu, tempeh and other plant-based proteins, or a section could potentially be added along the lines of 'other protein foods'. Mushrooms are typically included as a vegetable within FBDG due to their culinary use. To ensure understanding and easy application to everyday food habits, effective communication of FBDG should be considered. For example, quantifying the number of weekly or daily portions of mycoprotein that should be recommended or whether a general protein diversification message would be better.

Regarding the concept of 'alternative proteins', there was a view that this terminology is not universally accepted. An umbrella term such as 'other novel protein sources' could be more appropriate. Some protein foods are developed to mimic meat from a sensory perspective, thus are meat analogues which could also impact how they are represented in FBDG.

Consumer awareness was also explored with a generic view that the public may not understand what a fungal-derived protein is. There was a consensus that use of trade names such as Quorn or mycoprotein might be better accepted by the public rather than the term 'fungal protein'. Ongoing consumer education is warranted, so that consumers can differentiate between different dietary sources of protein and make informed choices (Box 5).

Discussion Statement 6. *The health science and nutrition data suggest that fungal-derived proteins should not be considered as ultra-processed, and classifying them as such would have a detrimental impact/effect on transitions to more sustainable diets.*

As many meat-alternative products are based on protein isolates and concentrates of different plant-based materials, many would be classed as ultra-processed if applying the NOVA classification system (Monteiro et al. 2018, 2019). However, it was agreed that the term 'ultra-processed' is not a globally accepted term to categorise foods in a way that is helpful from a public health and nutritional stance. Not all panellists were comfortable that the term 'ultra-processed' had been used in the statement, as it endorses use of the term. There was an overarching consensus that currently available definitions of ultra-processed introduce ambiguity into scientific discussions (Forde 2023; Forde and Decker 2022).

The recent UK Scientific Advisory Committee on Nutrition (SACN) statement (SACN 2023) on processed foods and health in 2023 reported that food processing has important roles including improving edibility, safety, shelf-life, preservation, palatability, retention of nutrients, modifying bioavailability (e.g., through micronutrient fortification) and convenience. Application of UPF classifications raised practical concerns and was found to be discordant with other nutritional and food-based classifications (SACN 2023).

One panellist had the view that UPF is a socio-political term that offers little in helping to guide public health. The rest of the panel agreed that the NOVA classification is not helpful for the nutritive, health, and sustainability dimensions of foods. It was concluded that focusing on nutrient density and nutrients of public health concern such as fat, salt and sugar represents a more objective and evidence-based way forward (Box 6).

Discussion Statement 7. *Consumers fully understand the role that fungi and fungal-derived proteins play in healthy, sustainable diets. There is no need for raising consumer awareness to change consumption behaviours.*

Lastly, there was a generic consensus that consumers do not understand the role that fungi and fungal-derived proteins play in healthy and sustainable diets. It was mentioned that we should be looking at sustainability as a matrix rather than focusing on protein specifically. Some publications are also now beginning to consider environmental footprints to deliver on health and environmental goals (Saget et al. 2021).

It was believed that consumers may not understand that mycoprotein is a complete protein, nor the health benefits of fungal-derived protein. There were also concerns that consumers could be at risk of micronutrient deficiencies without adequate guidance about how best to replace animal products. There was agreement that it is important to communicate the health benefits but also the risks when transitioning to diets where protein is derived predominantly from non-animal sources. Overall, it was agreed that more data on current consumer and non-consumer understanding of fungal-derived proteins as part of healthy, sustainable diets is needed (Box 7).

6 | Discussion and Conclusions

The roundtable discussion identified areas of consensus, disparities, misunderstandings and future research directions. Regarding the categorisation of fungi and where to best place fungal-derived protein in FBDG, several viable points were

BOX 5 | Areas of consensus for Discussion Statement 5.

- Any pending updates or developments to FBDG should be 'future proofed'.
- A segment for '*other novel protein sources*' could be one viable way to 'future proof' protein categories.
- There was consensus that the term mycoprotein or brand names are preferred by consumers rather than fungal-derived protein. However, this has other limitations that may prevent the use of these descriptors, particularly the use of brands.
- We need to consider how 'other novel protein source' messages are communicated within FBDG to ensure that these are understood and can be applied by the lay public from a practical stance.

BOX 6 | Areas of consensus for Discussion Statement 6.

- The panel reached a consensus that there remains poor agreement in the scientific community with regard to the definition of ultra-processed foods.
- The definition of ultra-processed food is subjective and ambiguous and in its current form, lacks the accuracy to inform a differentiation between foods based on their nutritional, health or sustainability credentials.
- The ultra-processed food term has negative connotations that may unfairly demonise otherwise healthy and sustainable alternative protein sources and may act as an unnecessary barrier in supporting consumers in making the transition to healthier and more sustainable dietary patterns.
- Rather than describing foods based on their degree of processing, a more objective approach is to describe foods by their nutrient content.

BOX 7 | Areas of consensus for Discussion Statement 7.

- There is a need for raising consumer awareness about fungal-derived proteins to inform consumption behaviours.
- When transitioning to more sustainable diets, consumers need to be aware of the benefits but also of any potential health risks, particularly micronutrient deficiencies in unbalanced plant-based diets.
- More research on consumer understanding of non-animal derived proteins is needed.

raised. It was agreed that the fungal kingdom is distinct with a long history of use. However, application of its terms of use may need to be different when communicating to the public compared to botanical or ecological use. It was agreed that fungal protein could fall effectively under a 'non-animal derived' food category or form part of a generic protein diversification message. The latest Nordic Nutrition recommendations under the 'dietary sources and intake' section for protein differentiate between 'animal protein' and 'non-animal protein'(NC 2023), where fungi (in the form of mycoprotein) is listed under the non-animal protein reference (NC 2023).

Next, regarding the quality of fungal compared to animal protein it was generally thought that mycoprotein was not inferior. This consensus has been reinforced by randomised control trial evidence with older adults showing that a mycoprotein-based vegan diet supports equivalent rates of daily MPS when compared with an omnivorous control (Monteyne et al. 2023). It was discussed how we should look at 'whole diets' and shortfalls in amino acids from a sole food could be counteracted by the variety in the diet. This message has been emphasised by Katz et al. (2019) who explained that we eat 'mixed' diets with different protein sources containing an array of amino acids, meaning that it is the overall diet that will determine protein adequacy (Katz et al. 2019). It was agreed that further research with other fungal strains, ready to eat mycoprotein products and longer-term studies are needed.

In relation to the inclusion of fungal-derived proteins within a general 'protein diversification' message, this statement appeared to be mostly well accepted. It is recognised that the category 'plant-based protein' is currently the most well-recognised group of alternative proteins, yet there is scope for further diversification, and fungal, plant, algal, bacterial, cultured and insect-based proteins could all have a role to play (Moura et al. 2023). There was agreement that two umbrella categories of animal/animal-derived and non-animal/non-animal derived could work and be useful from a health and environmental perspective.

In terms of evidence, it was agreed that for mycoprotein there is enough health and environmental research to warrant its inclusion within FBDG. However, more research needs to be undertaken across a wider collection of population groups, for example, children, women of childbearing age, and men and women of advanced age. A stepwise approach is usually adopted when compiling FBDG, which includes: (1) identifying diet-health relationships, (2) identifying country-specific diet-related health perturbations, (3) identifying nutrients important to public health, (4) identifying foods relevant for FBDG, (5) identifying food consumption patterns, (6) testing and then optimising FBDG, and finally (7) visual/graphical representations of FBDG (EFSA 2010). There was no evidence to suggest that fungal-derived proteins should be excluded from FBDG.

In terms of their positioning within FBDG, several viable points were raised. Primarily, it was agreed that any update to FBDG should be 'future proofed'. Given the acceleration of change with novel protein foods coming into the market, it was proposed that: (1) an animal-derived protein section and/or a (2) non-animal derived protein section or (3) other protein sources sections could be adopted. It was agreed that using the phrases 'mycoprotein' or a brand name may be more appealing to consumers than 'fungal-derived', however both come with their limitations particularly using a brand name. It was thought that the term 'fungal-derived' may have unpleasant connotations unrelated to foods and this merits research into consumers' views. It was stipulated that any changes to FBDG need to be easily applied from a practical stance by the lay public. There was an agreement that visual/graphical representation is important alongside documented updates in supplementary guides.

The discussion on ultra-processed foods was in full agreement. It was agreed that the NOVA classification of UPFs is ambiguous, subjective and cannot be applied to guide consumer choices to healthier and more healthy and sustainable diets in the UK or other populations with similar dietary patterns from high-income countries (Forde and Decker 2022; Forde 2023). This viewpoint aligns with the SACN (2023) statement on processed foods and health (SACN 2023) and recent British Nutrition Foundation roundtable on healthier processed foods (Lockyer et al. 2023).

In relation to consumers' understanding of fungal-derived proteins, it was agreed that additional education campaigns are needed. In particular, the health and sustainability credentials need to be better explained alongside the benefits and potential negative implications of transitioning to the use of non-animal protein sources. Some consumer research has already been undertaken (Chezan et al. 2022; Dean et al. 2022; Hellwig et al. 2024), but further research is needed.

Finally, the panel discussed future research directions. There was overarching agreement with the need to conduct long-term, well-designed population studies and include plant-based, as well as meat-based comparators when studying fungal-derived food proteins. More short-and long-term studies are needed to investigate shifts from animal-based foods to plant-based foods in general using standardised nutrition and environmental impact assessments (Najera Espinosa et al. 2024). As shown in Table 3, some more specific, targeted areas for future research were discussed. This included diet modelling to better comprehend the effects of protein transitioning (to both fungal and plant-derived protein sources) and any unintended consequences, such as the impact on micronutrient intakes and status. In addition, further short-and long-term trials are needed in specific population subgroups such as older consumers, young children and during

TABLE 3 | Fungal-derived protein research gaps.

• There is a need for more longitudinal and population-based studies evaluating intakes of non-animal derived protein (mycoprotein and plant-based) in relation to broader markers of health, such as immune functioning and cancer risk.
• Research across key growth and developmental life stages would be beneficial, such as childhood, the childbearing years and advanced aging.
• Given the chitin, beta-glucan, and fibre profile of mycoprotein, there is scope to further study aspects of gut health, for example, transit time in children.
• Much of the research has tended to focus on the *Fusarium venenatum* fungal strain (the original strain used to produce mycoprotein). It would be useful to establish whether protein production using other strains results in similar health outcomes.
• It would be helpful to use additional plant-based comparators (e.g., soy- and pea-based products) in RCTs using mycoprotein.
• Nutrient databases need to be updated regularly to include the array of emerging non-animal derived foods, or at least well-established core brands.
• There is potential to use dietary survey data to better understand intakes of non-animal derived protein and inter-relationships with nutrient intakes and markers of health.
• There is scope to further study consumers' understanding of non-animal derived proteins and where these fit in the diet.
• Diet modelling on nutrient adequacy and bioavailability is needed to better understand the effects of transitioning to non-animal derived food proteins and potential unintended consequences in relation to micronutrient intakes and status.
• Different companies producing mycoprotein may have different sustainability and health credentials, which would need to be investigated separately.
• It would be helpful to investigate the non-nutrient fractions in mycoprotein, such as phenolic acids, and whether these impact nutrient bioavailability or health.

pregnancy. The need to research broader health outcomes and different fungal strains was also discussed.

7 | Conclusions

Overall, the alternative/non-meat protein food sector, which includes fungal-derived mycoprotein, is a growing and advancing sector. In fact, the rate of change appears to be exceeding the boundaries of current FBDG. The present roundtable discussion recognised that mycoprotein is an established and viable food source. Clearly, data on the latest habitual intakes along with ongoing population studies comparing different protein intake forms against health and sustainability outcomes are warranted. However, in the meantime there is no good reason to exclude mycoprotein from FBDG. Indeed, having a 'non-meat' or 'other protein' section, or a generic protein diversification message, as part of FBDG could be a viable way forward to achieve health and sustainability goals.

Author Contributions

E.J.D. wrote up the first draft of the manuscript based on the information presented and discussed at the roundtable meeting. All listed authors reviewed and contributed to the content of the final manuscript. PS and SNE attended the roundtable and provided comments on the write-up.

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Conflicts of Interest

This work was supported by Marlow Foods Ltd. provided a donation to the Nutrition Society to cover travel and meeting costs and Dr. Hannah Theobald (HT) and Dr. Louise Durrant (LD), employees of Marlow Foods Ltd., along with Dr. Emma Derbyshire (ED), shaped the programme, but HT and LD were not present at the event. Professor John Brameld chaired the meeting and has worked with AB Agri/AB Vista/Livalta, Beta Bugs, Calysta, MicroHarvest, Oko Protein Ltd. and Ynsect on various projects in the area of alternative proteins. Dr. Emma Derbyshire, Nutritional Insight Ltd. an independent consultant to Marlow Foods Ltd., helped to organise the member-led meeting, developed the meeting agenda and statements for debate, collated the pre-read material and identified and invited speakers, panellists and observers. She compiled the first draft of the publication and circulated this to co-authors for comment. Dr. Emma Derbyshire has consulted across a range of food sectors including the Agriculture and Horticulture Development Board (AHDB), American Pistachio Growers and British Egg Industry Council. Nutritional Insight has received Innovate UK Funding. Professor Benjamin Wall has received research funding, travelling expenses and/or speaking honoraria from Quorn, Science in Sport, Nutricia, Futureceuticals and the Gatorade Sports Science Institute. Professor Paul Thomas is the managing director of Mycorrhizal Systems Ltd. Professor Ciarán Forde has received research financial support from the TKI Top Sector Agri-Food program (NL) for public-private partnership projects (current LWV22098, LWV22150) and reports both paid and non-paid relationships with Kerry Taste and Nutrition, PepsiCo, Mondelez, Lesaffre, Ferrero, Ajinomoto, United States Department of Agriculture, General Mills, GB Foods, ILSI-SEA, Institute for Food Technologists, Nutrition Society, World Sugar Research Organisation and the Northern Irish Dairy Council, which includes consulting/advisory, speaking fees and travel reimbursement. Professor Wendy Hall reports consultancy for Zoe Ltd. Professor Tom Hill is a holder of past and current UKRI (Innovate UK) funding for commercially focussed research with Noble Foods ltd, DSM ltd, Infarm ltd, Roboscientific Ltd., M&S Plc and Fyto Ltd. He has ongoing university facilitated consultancy with Noble Foods ltd and Co-I in a BBSRC funded Diet and Health hub 'Start Healthy Stay Healthy' Hub [led by Uni of Surrey]. Dr. Andrea Glenn has received honoraria and/or travel support from the Academy of Nutrition and Dietetics and Vinasoy, and Research Funding Support from the Canadian Institutes of Health Research and Diabetes Canada. Dr. Jenny Paxman declared that Quorn Foods were sponsors for the 2022 Nutrition Society Summer Conference for which she was lead local organiser. Dr. Pauline Scheelbeek has no conflicts of interest to declare. Ms. Ursula Arens has no conflicts of interest to declare other than membership of the British Dietetic Association sustainable diets group. Ms. Sarah Nájera Espinosa has no conflicts of interest to declare.

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Data sharing is not applicable to this publication as no new data were created or analysed.

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