Feed Our Future – an opportunity to discuss the science of sustainable food systems –

Warren McNabb .......................................................................................................................... 33

Nutrition comes first

Back to the future food systems – Barbara Burlingame .......................................................... 35
Healthy and sustainable diets: providing nutrition, not only nutrients – Thom Huppertz ......... 38
The availability and affordability of nutrition – Nick W. Smith .............................................. 41
Discussion Session 1 ..................................................................................................................... 44

The current food system conversation

Origin of the current conversation: An exploration of the animal/plant divide – Frédéric Leroy .... 45
Producing animal source food with respect for human and planetary health –
Hannah H.E. van Zanten, Benjamin van Selm, Anita Frehner ................................................. 48
Discussion Session 2 ...................................................................................................................... 51

Food systems impact

Our connected future with the turn-key technologies that are reducing food waste and
improving nutrition – Wayne Martindale .................................................................................... 52
Environmental footprinting of New Zealand agricultural products and implications for
food nutrition – Stewart F. Ledgard .......................................................................................... 55
Discussion Session 3 ...................................................................................................................... 59

Changing the food system?

The changing face of protein production – Paul Wood and Mahya Tavan ............................... 60
Consumers are central to any change in the food system – Joanne Hort ................................. 63
Discussion Session 4 ..................................................................................................................... 66
Overall conclusion on the audience discussions ......................................................................... 67

Concluding commentary

Feeding the future: Reflections on the food systems discussion – John Roche .......................... 68

Congratulations – Allen Petrey .................................................................................................. 71

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Feed Our Future – an opportunity to discuss the science of sustainable food systems

Professor Warren McNabb*,
Sustainable Nutrition InitiativeTM, Riddet Institute,
Massey University, New Zealand

The Riddet Institute’s Feed Our Future event, held at Te Papa in Wellington (9 June 2021), was a fantastic opportunity to bring together New Zealand policy makers, business, and science, for a conversation that is very relevant to all New Zealand. As a net food exporting nation, New Zealand plays an important role in the global food system and in many cases does so exceptionally well. But the sustainability of our domestic food production and consumption is facing considerable pressure. Whilst New Zealand is well known for the quality of the foods we export, we are increasingly seeing evidence of domestic shortages of foods and specific nutrients, and we are aware of increasing environmental sustainability and perceived health issues. Consequently, the future sustainability of our food production is something that must be considered by all those making decisions about our national food system, and this is increasingly on the minds of all New Zealanders.

Sustainability means different things to different people. For many, it brings to mind thoughts of greenhouse gases and water quality, to others it is all about getting enough food to be adequately fed on a daily basis. But sustainability has to be more holistic than simply environment or health or economic outcomes. A sustainable practice (in this case the global food production system) is one that will continue indefinitely into the future; one that still serves our great-grandchildren as well as, or better than, it served us. Thus, for a food system to be sustainable, it must feed people, provide incomes, be socially acceptable, and not compromise the natural resources on which it depends.

At Feed Our Future, we attempted to bring together speakers who could cover many aspects of a sustainable food system. This had its challenges, given the huge complexity that surrounds the sustainability of global food production. The reality is that we could only scratch the surface but our aim was to get the conversation started. There were many more voices that we would have liked to include, had we a longer time. However, we would like to thank all of our speakers for their efforts in preparing their talks for the event, and manuscripts for this publication. We asked each of them to be accessible and evidence-based, and to provoke discussion. The quality of the discussion in the room attested to their success. This publication is our attempt to continue that conversation. The speakers’ talks are also available on our website.¹

Again, were we not limited by the capacity of a room, we could have invited many more. There was certainly the interest to attend. By providing recordings of the talks online and summaries of the discussion sessions here, we hope that those who could not attend in person can still benefit from the event. We would also like to thank those who did attend for engaging in the discussion and providing valuable insights and feedback on what they heard.

Feed Our Future was organised by the Sustainable Nutrition InitiativeTM (SNi) research program at the Riddet Institute. Our research focusses on the question: “How does the world feed the world?” Part of this research is in the development of the Feed Our Future – an opportunity to discuss the science of sustainable food systems

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¹Video recordings of all talks from the event are available at: https://www.riddet.ac.nz/feed-our-future-a-new-zealand-sustainable-food-systems-dialogue-event/

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DELTA Model, a publicly-available scenario-testing tool, which allows users to design a global food production system and to see how this measures up against the nutritional requirements of the global population. The model has generated some valuable insights about the current and future global food system.

For example, of the food mass available globally for human consumption, 75% is plant-sourced, the remainder being animal-sourced. This reflects the fact that over 9 billion tonnes of plant food commodities are produced on farms globally each year, compared to around 1.5 billion tonnes of animal-sourced food commodities. One reason for the change in ratios between production and consumption is waste: over 90% of food waste along the supply chain and in home is plant matter.

Plant foods supply the majority of global nutrient availability for most nutrients. The exceptions are things like vitamin B12, calcium and some essential amino acids, which are largely sourced from animal foods. The complementarity of plant and animal production systems, and the complementarity of their products for good nutrition, is an important factor to consider.

When examining global food production and distribution in 2018, the DELTA Model calculated that there is already sufficient energy and protein availability for the current global population. Indeed, there is enough for a further 1 billion people. However, practically we know that there is both over- and undernutrition around the world. This malnutrition reflects the inequity of food distribution in the current global food system. We have not been able to model these issues and so they are not reflected in the DELTA Model. However, recognising these limitations, the model does clearly show that we currently produce adequate levels of macronutrients globally.

An unexpected outcome from the model was the importance of considering micronutrients and trace elements when thinking about adequately feeding the global population. The model suggests there is insufficient calcium and vitamin E available currently to meet the requirements of the global population, even if distributed equitably. Other nutrients, including iron, potassium, zinc and vitamin A and B12 were close to deficient, implying that widespread deficiency will exist, given our current inequitable food distribution.

Furthermore, reducing food waste along the supply chain and in home did not resolve these nutrient gaps when modelling that scenario. We waste less of the foods rich in these micronutrients than we do of foods rich in energy or fibre, so reducing food waste has a differing impact on the availability of different nutrients.

Many have suggested that reductions in the consumption of many animal-sourced foods will be necessary to prevent great damage to our health and environmental sustainability. While the details of these outcomes are uncertain and are topics desperately in need of sensible, fact-based scientific discussion, the DELTA Model at least, allows us to examine what changes to global food production will mean for the adequacy of nutrient supply for human nutrition in the future. Animal-sourced foods currently contribute a quarter of global food mass for consumption but deliver disproportionately high proportions of the global availability of protein, fat, calcium, phosphorous, selenium, zinc, vitamins A, B2, B5, B12, and all of the bioavailable indispensable amino acids. Our findings with the DELTA Model indicate that reductions in animal production as the global population increases will make meeting global nutrient requirements very difficult, due to the nutrient density of these foods and their role in delivering key nutrients not as easily available from plant-sourced foods. This motivated the coining of the phrase "plant-based and animal-optimised", as the goal for what the food system should aim to be. This is not driven by greater support for animal-sourced foods but reflects a reality that to balance global nutrient supply and deliver sustainable nutrition to the global population, the right balance of plant and animal sourced foods will be required.

This is not to say that animal-sourced food consumption by individuals should increase or decrease. Individuals must meet their own nutrient requirements in the way that best suits them, based on their own choices and values. A vegan diet for example, is perfectly feasible for those with the knowledge and income to do it well. What our research does tell us is that, on a global scale, it is difficult or impossible to produce sufficient micronutrients and trace elements to meet the global demands for these nutrients without animal production. Macronutrient supply would not be the problem; it would be adequate micro-nutrient availability that would be the greatest challenge under an entirely plant-based production system.

Looking to the future, we have high expectations for what SNi can achieve. We are currently building resource footprints into the DELTA Model, starting with land use, so that a user can assess the environmental feasibility of the scenarios they simulate. Elsewhere, we are working with our partners to assess the importance of food trade to nutrition in different countries. We are also quantifying the difference in food composition in different parts of the world and what this means for local and international nutrition. Finally, the creation of a model for the New Zealand food system, to better analyse its sustainability into the future is an important future target for SNi.

Sustainable food systems and sustainable nutrition are exciting fields, attracting global attention. The United Nations Food Systems Summit, held this year to promote action towards sustainable food systems, demonstrates the importance of this science at the highest level. Any decisions made in this field must be evidence-based, or risk jeopardising the ability of the food system to deliver nutrition for all. With events like Feed Our Future, we hope to continue to bring the science to the forefront of decision-making. This is too important a topic not to be at the forefront for discussion in New Zealand.
Through a broad historical lens, modern agriculture is a recent experiment. By some measurements, it has been successful; by other measurements, it has been a catastrophic failure. Regardless, for scientists and policy makers involved in recent global summits, international committees, UN conventions and commissions, and independent panels of experts, the sustainability of food systems and diets necessitates a re-examination of the past to inform the future.

Sustainable food systems and sustainable diets both seem to be new and modern frontiers. The fact that these terms are now in common use is new, but they are not new as concepts or as imperatives for action – they’ve simply migrated into mainstream awareness.

One could go back in time more than two millennia and find alignment with the Greek philosophers for the concepts of sustainable diets and food systems. As for the modern science of nutrition, our glance to the past can take us back 150 years to the pioneer Ellen Swallow (aka Richards). She holds several distinctions dating from the late 19th century: she was the first female admitted to the prestigious Massachusetts Institute of Technology, she is credited with introducing the word ‘ecology’ into the English language, and she introduced nutrition science into university-level curricula under the name ‘human ecology’. In her work, the studies related to agriculture, human health, and the natural and physical environment were integral to the subject of human nutrition. Over several decades after Ellen Swallow, integrated disciplines devolved into segregated sciences, to the detriment of all. As the degradation/destruction of natural environments and the epidemics of obesity and diet-related chronic diseases progressed, with modern agriculture at their epicentre, attempts were made to reinstate sustainable diets and sustainable food systems for policies and actions.

Notwithstanding the pleas from many quarters dating back to the 1960s and 1970s, e.g., Rachel Carson’s Silent Spring (1962), the first UN conference on the environment in 1972, and the Club of Rome’s Limits to Growth and the dire warnings about overshooting planetary limits (1972), and the Rio Earth Summits in 1992 and 2012, there have been plenty of examples from the nutrition science community, since the days of Ellen Swallow, to bring to the fore the topic of sustainable diets and sustainable food systems. Some selected examples include the following.

Dietary Guidelines for Sustainability (Gussow and Clancy, 1986): ‘…educated consumers need to make food choices that not only enhance their own health but also contribute to the protection of our natural resources. Therefore, the content of nutrition education needs to be broadened and enriched not solely by medical knowledge, but also by information arising from disciplines such as economics, agriculture, and environmental science.’

The International Union of Nutritional Sciences International Congress of Nutrition (Wahlqvist, 1994): The overarching conference theme was Nutrition in a Sustainable Environment, with sessions including climate change and food production, sustainable food production, burdens of terrestrial and oceanic pollution.

The New Nutrition Science Project (Cannon and Leitzmann, 2005): ‘…broad integrated structure brings much recent and current progressive work into the centre of nutrition science…concerned with personal and population health, and also with planetary health – the welfare and future of the whole physical and living world…contribution to the preservation, maintenance, development and sustenance of life on Earth, appropriate for the twenty-first century.’

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Basic unit of nutrition

Perhaps the most widely used definition of nutrition identifies individual nutrients per se as the basic unit, with nutrients defined as being substances required for the maintenance of life and growth. This definition originates in the health sector where the intakes of nutrients below requirements lead to disease states. This health sector conceptualisation has led to interventions bypassing diets and food systems as solutions, and focusing on medicalised treatments with individual nutrients in the form of pills, injections, or therapeutic formulations. Flaws in this approach are many, including the fact that substances identified as nutrients represent only a tiny subset of beneficial bioactive components in a diverse diet, and that a measured deficiency of a nutrient is almost always simply a marker for a poor quality diet overall. Promoting nutrients as the basic unit of nutrition is easily exploited, and has directly led to the appropriation by the food industry of the term ‘healthy’ for a range of ultraprocessed foods, i.e., highly refined foods dosed with nutrients manufactured by the fine chemical industries.

The agriculture sector had long considered food per se as the basic unit of nutrition, the metric for which was dietary energy supply (de Haen, Klases and Qaim, 2011). It was the crude but useful methodological tool for monitoring food security, but it was misused with the stated presumption that if food intake (i.e., dietary energy) is sufficient, everything else (e.g., micronutrients) will also be sufficient. Obviously, this is a deeply flawed approach, with decades of examples in the nutrition literature of dietary energy sufficiency and even excess, combined with micronutrient malnutrition in the same individuals—a striking example of which is children who are both obese and stunted (Fernald and Neufeld, 2006).

It was the environment sector that succeeded in finally bringing the concept of sustainable food systems back into the mainstream of nutrition awareness, with their game-changing ‘cross-cutting initiative on biodiversity for food and nutrition’ (Conference of the Parties, 2006), which included the specific request that the initiative be led by FAO’s nutrition division. This then brought to bear the re-introduction of diets, and explicitly sustainable diets—not foods, and not individual nutrients—as the basic unit of nutrition.

Healthy diets v. sustainable diets

The first scientific symposium on sustainable diets, in 2010 (FAO, 2012), included two breakout workshops, one of which was charged with developing a consensus definition for sustainable diets, which had been identified as an urgent requirement for moving forward (Sustainable Development Commission, 2009). The consensus definition is as follows:

Sustainable Diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimising natural and human resources (FAO, 2011).

There are fundamental distinctions between a healthy diet and a sustainable diet: a sustainable diet, by definition, is healthy; whereas a so-called healthy diet need not have anything to do with environmental sustainability. Similarly, an environmentally sustainable food system does not necessarily produce a sustainable diet, whereas a sustainable diet, by definition, requires a sustainable food system.

Indeed, the supermarket shelves are filled with foods synthesised in a food science laboratory and bearing front-of-pack labels and symbols signifying that they are healthy. It is for this reason that some authors have called ‘healthy’, as related to foods and diets, a bankrupt concept (Sukol, 2016).

Traditional food systems of indigenous peoples have a place of great importance in science-policy forums and for assessments of future food systems (Kuhnlein et al., 2009; 2013; FAO, 2021a). Unfortunately, the contributions that these knowledge systems can make are often rejected, with the justification that they do not conform to evidence-based policy development using the conventional hierarchy of evidence. In many areas, and particularly for food and food systems, a rethinking is necessary to give traditional knowledge greater consideration (Milbank et al., 2021). The recent White/Wiphala Paper on Indigenous Peoples’ food systems (FAO, 2021b) makes the case convincingly that the often-used assessment of evidence developed by clinical/medical sciences has criteria that are inappropriate for food systems policy development; it makes the following recommendations: (1) that traditional knowledge systems need to be recognised, respected and valued with equal consideration and integration by the scientific and academic communities informing the UN Food Systems Summit, and beyond; and (2) the contribution by itself of systemic observation carried by Indigenous Peoples’ traditional knowledge is a tested scientific approach.

The year 2021

The year 2021 is significant in many ways. A few years earlier, the UN General Assembly declared that 2021 would be the International Year of Fruits and Vegetables (IYFV). This is a welcome departure from previous food-themed international years where single starchy staples featured because of their importance for food security—that is, global dietary energy supply. Examples include the International Year of Rice (2004) and the International Year of Potato (2008). The year 2013 was the International Year of Quinoa, the first attempt at recognising the importance of lesser-known, but regionally important crops; albeit still a starchy staple. The IYFV brings to the fore the importance of the first principle of good nutrition: eat a variety of foods. It also elevates micronutrients to the same level of importance as dietary energy.

The year 2021 is also the year of the UN Food Systems Summit (FSS). Unfortunately, there seems to be little or no attempt to revisit the past to inform the future. Critical reviews and analyses and past summits—their recommendations and degrees of implementation, their successes and failures—have not been undertaken. This should be the single most significant undertaking of the FSS—examining the past to inform the future—the absence of which is, perhaps, the single most significant shortcoming.

References


Introduction

The primary purpose of the food system is abundantly clear: providing healthy diets to a world population within planetary boundaries. However, the routes towards this goal are less clear and heavily debated. Within this context, the replacement of animal-based products with plant-based products is often advocated, but such recommendations are often made on the, rather reductionist, consideration of animal-based products mainly as a protein source, and do not consider the broader context of nutrients and nutrition provided by different food products. As such, a product-for-product replacement based on a single nutrient may lead to further impact in the diet, leading to nutrient deficiencies. Furthermore, it is important to keep in mind that nutrients in food products should not only be considered quantitatively (i.e., the concentration of a nutrient) but also qualitatively (i.e., the nutrient being present in the right form to contribute to nutrition). Unfortunately, many approaches that have been applied focus primarily (or even exclusively) on nutrient quantities, and not nutrient quality, which can have notable impact on human nutrition and health.

Nutrients and nutrition

Although food items are consumed by people for a variety of reasons, their primary importance is that they are a source of nutrients and thus contribute to nutrition. The distinction between nutrients and nutrition is important: nutrition can be defined as the process in which an organism uses food to support its normal growth, development and maintenance of health via ingestion, absorption, assimilation, biosynthesis, catabolism and excretion. Food items are the source of nutrients used for this purpose, but nutrition entails much more than solely the ingestion of nutrients. In other words, nutrients are essential for nutrition, but nutrients alone are not sufficient.

Nutrient bioavailability: calcium as an example

As outlined in the previous section, the ingestion of nutrients alone is not sufficient to provide nutrition, and a key step in this is that they need to be bioavailable. Bioavailability is a crucial parameter for almost all micronutrients, including minerals and vitamins. In some cases, this is also considered in recommended daily intake (RDI) values, i.e., in the case of iron and zinc. For iron, an RDI of 14 mg is recommended for diversified diets, rich in meat fish, poultry, and/or rich in fruit and vegetables, whereas for diets rich in cereals, roots or tubers, with some meat, fish, poultry and/or containing some fruit and vegetables, the RDI is 22 mg (CODEX, 2017). Likewise, for zinc, the RDI is 11 mg for mixed diets, and lacto-ovo vegetarian diets that are not based on unrefined cereal grains or flours with high extraction rate (>90%), but 14 mg for cereal-based diets, with >50% energy intake from cereal grains or legumes and negligible intake of animal protein (CODEX, 2017). In both cases, the

Thom Huppertz holds an MSc from Wageningen University and a PhD from University College Cork. Prof Huppertz’s research career includes academic and industrial research in the field of dairy science and technology, with dairy chemistry and physics as a central theme. His research topics have ranged from biosynthesis of milk constituents to digestion of dairy products in the human body, and from product and process optimisation to the role of dairy products in a healthy sustainable diet and nutrient quality and bioavailability. He currently combines the roles of Professor of Dairy Science and Technology at Wageningen University, Principal Scientist at FrieslandCampina, Visiting Professor at Victoria University of Melbourne, and Editor-in-Chief of the International Dairy Journal.
RDI is adjusted based on the main sources of the nutrient and considers, e.g., the higher bioavailability of iron and zinc from animal-based products (Solomons, 1982; Hurrell & Egli, 2010; Platel & Srinivasan, 2016). However, such diet-dependent RDI values are not considered for other micronutrients, despite the fact that differences in bioavailability are clearly apparent.

Calcium, in this respect, forms an interesting example: calcium is an indispensable micronutrient that is required by the body for bone health, teeth, and many biochemical processes. Compared to most other micronutrients, calcium requirements are comparatively high, with RDI values of approximately 1 g per day for adults (CODEX, 2017; EFSA, 2017). Meeting these requirements thus requires food products that are comparatively rich in calcium and that allow them to be met without excessive energy intake. Some examples of food products including their calcium content, also expressed on a caloric basis, as well as their Ca per serving, are shown in Table 1. From this, it is clear that approx. 3 servings of milk per day are required to achieve the aforementioned RDI, whereas many more servings of other products are needed. For broccoli, this would also entail a notable increase in caloric intake. For spinach, Ca/energy ratio is favorable, but the low concentrations would require high intake.

Table 1: Ca content of selected food products (data from the Dutch Food Composition Database (NEVO) published by the National Institute for Public Health and the Environment, RIVM (https://www.rivm.nl/en/dutch-food-composition-database/access-nevo-data/nevo-online)).

<table>
<thead>
<tr>
<th>Food item</th>
<th>Ca (mg/100 g)</th>
<th>Energy (kcal/100 g)</th>
<th>Ca/energy (mg/kcal)</th>
<th>Serving size (g)</th>
<th>Ca/serving (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>124</td>
<td>61</td>
<td>2.0</td>
<td>250</td>
<td>310</td>
</tr>
<tr>
<td>Cheese</td>
<td>740</td>
<td>379</td>
<td>1.9</td>
<td>20</td>
<td>148</td>
</tr>
<tr>
<td>Broccoli</td>
<td>38</td>
<td>27</td>
<td>1.4</td>
<td>45</td>
<td>17.1</td>
</tr>
<tr>
<td>Spinach</td>
<td>105</td>
<td>26</td>
<td>1.7</td>
<td>80</td>
<td>84</td>
</tr>
</tbody>
</table>

In many Western diets, dairy products are the main source of dietary calcium. For example, in the Netherlands, close to 60% of all dietary calcium is supplied via dairy products. However, in other countries where dairy consumption is notably lower, other product categories become more dominant sources of calcium. For example, in many countries in South-East Asia and Sub-Saharan Africa, plant-based products are the main dietary source of calcium (DELTA model: https://sustainable-nutritioninitiative.com/sustainable-nutrition-initiative/; Smith et al., 2021). When considering products as a source of calcium, not only calcium content, but also bioavailability should be considered. Table 2 highlights bioavailability of calcium from the same products as are shown in Table 1. From this, it is clear that (1) bioavailability is never 100%, and only exceeds 50% for broccoli, and (2) there are wide variations between products. Some products (e.g., spinach (Table 2), but also rhubarb, beans, seeds, grains) have notably lower bioavailability of calcium, which can be related to the presence of oxalate or phytate in such products (Weaver et al., 1999). These compounds bind calcium strongly and impair its absorption in the body. From this perspective, it is important to recognise that RDI values for calcium are based on calcium balance studies conducted mainly on Western diets (FAO, 2002), which, as outlined earlier, are rich in dairy. For non-Western diets, which often derive a much higher proportion of calcium from non-dairy sources, RDI values for calcium may thus need to be elevated further. Likewise, for vegan diets, higher RDI values for calcium also appear warranted to compensate for lower bioavailability, as is also done by CODEX (2017) for zinc and iron.

**Nutrient quality: protein quality as an example**

Although protein is often considered to be an indispensable nutrient, it is really its building blocks, i.e., the amino acids, that are the indispensable nutrients. More specifically 9 out of the 20 amino acids (Val, Leu, Ile, Lys, Phe, Trp, Lys, Met and Thr) cannot be synthesised by the human body and thus need to be provided via food. The other 11 amino acids can be synthesised by the human body and are thus not deemed indispensable. However, their synthesis does require sufficient dietary nitrogen, for which protein is also the only dietary source. Therefore, from a dietary perspective, proteins should be considered as both a source of indispensable amino acids (IAA) and nitrogen (FAO, 2013). Of course, for both to be utilised efficiently, they need to be absorbed. The ability of a protein to supply sufficient levels of IAA and nitrogen in absorbable form is typically referred to as protein quality.

Protein quality has been measured in different ways over the years. From the early 1990s, the protein digestibility-corrected amino acid score (PDCAAS) became the global standard, based on recommendations by FAO. The method has, however, to a large extent been superseded by the digestible indispensable amino acid score (DIAAS). The main advantages of DIAAS over PDCAAS are that it is based on ileal rather than fecal digestibility and that it measures amino acids individually, rather than measuring total nitrogen and assuming every amino acid to have the same digestibility factor, as is done in PDCAAS (FAO, 2013; Moughan & Wolfe, 2019). Obtaining a DIAAS score for a protein source requires the following information (FAO, 2013):

1. Amino acid composition of the protein (expressed in mg/g protein)
2. Standardised ileal digestibility (SID) of each IAA
3. A reference amino acid pattern for the IAA (expressed in mg/g protein)

From (1) and (2) above, the amount of digestible amino acid can be calculated for each IAA and by comparison to the reference pattern from 3, and a scoring pattern for each IAA can be calculated. In DIAAS, the most limiting IAA (i.e., the lowest score compared to the reference pattern) is considered the value for protein quality, and expressed as either a ratio or a percentage of the reference pattern. In other words, a DIAAS score of 1 (or 100%) indicates that all IAA are supplied in digestible form at the required level, whereas a score <1 (or <100%) indicates that...
at least one IAA is not provided in digestible form at the required level via the protein. This can be because the protein does not contain sufficient amounts of this IAA, its digestibility is low, or a combination of these. DIAAS values >1 (or >100%) are also possible. In this case, all IAAs are present at digestible levels above the requirements. This should, however, not be taken as an indication that less of a protein with a DIAAS score of 1.2 needs to be consumed than with a score of 1.0, as in the former case, nitrogen levels rather than specific IAA can become limiting.

DIAAS scores have been determined for a wide range of protein sources. An overview of some reported scores is provided in Table 3. In addition to the DIAAS score, this table also includes the first limiting IAA and the SID of that IAA. From Table 3, it is clear that there is a wide variety in DIAAS scores for different protein sources. In general, animal-derived sources score rather high on DIAAS, with scores typically exceeding 90%. For plant-based protein sources, much more variation is observed. While the soy protein score is relatively high, other sources, such as e.g., rice, wheat and sorghum score much lower.

Consideration of protein quality, however, should not be limited to a single score for a protein source based on a single IAA, as this ignores another key aspect, i.e., the complementarity of different protein sources. Many plant proteins, for example, lack sufficient levels of digestible Lys, whereas many animal protein sources contain a notable excess of digestible Lys (Moughan, 2021). Consumption of these sources together in a meal can thus lead to complementarity, where one protein source can compensate for deficiencies in another protein source. A key example of this is, for example, in a typical cereal-based breakfast with milk or yoghurt, where the excess Lys from the latter can compensate for deficiencies in the former, thus highlighting a strong synergy between plant-based and animal-based protein sources. It is crucial, however, that such complementarity is considered on a meal basis, and not a dietary basis.

Conclusions and future perspectives
Our global food system will undoubtedly be changing in the future, but its primary aim of providing healthy diets for the world population will certainly not change. These healthy diets include providing nutrients in digestible and bioavailable form to ensure that they can contribute to nutrition, and ultimately human health. Such aspects, however, appear to be readily over-looked in many, sometimes polarising, discussions on the topic of healthy and sustainable diets, with the risk of the quality of diets becoming a deprioritised factor. Balanced considerations of configurations of potential future food systems including not only the provision of nutrients, but also nutrition, is therefore essential to safeguard human health for now and generations to come.

Table 3: DIAAS scores from selected protein sources, including the first limiting amino acid (FLAA) and the standardized ileal digestibility (SID) of the FLAA

<table>
<thead>
<tr>
<th>Protein source</th>
<th>DIAAS (%)</th>
<th>FLAA</th>
<th>SID of FLAA</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skim milk powder</td>
<td>127</td>
<td>Met+Cys</td>
<td>94</td>
<td>Mathai et al. (2017)</td>
</tr>
<tr>
<td>Egg</td>
<td>122</td>
<td>Met+Cys</td>
<td>75</td>
<td>Heo (2012)</td>
</tr>
<tr>
<td>Beef (steak, pan-fried)</td>
<td>98</td>
<td>Val</td>
<td>99</td>
<td>Hodgkinson et al. (2018)</td>
</tr>
<tr>
<td>Pea protein concentrate</td>
<td>73</td>
<td>Met+Cys</td>
<td>78</td>
<td>Mathai et al. (2017)</td>
</tr>
<tr>
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<td>60</td>
<td>Lys</td>
<td>92</td>
<td>Cervantes-Pahm et al. (2014)</td>
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<td>Lys</td>
<td>73</td>
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</tr>
<tr>
<td>Sorghum</td>
<td>29</td>
<td>Lys</td>
<td>69</td>
<td>Cervantes-Pahm et al. (2014)</td>
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References
The key function of the global food system is to deliver nutrition to the global population. Therefore, when we are considering the sustainability of current and future food systems, nutrition should be prioritised.

There are many aspects to ensuring global nutrition, but I will address two key questions here. Firstly, are the foods that individuals need for adequate nutrition affordable, so that all individuals can meet their nutrient requirements with their income? Secondly, are the nutrients required by the global population delivered by the global food system?

The affordability of nutrition
A common approach to understanding whether nutrition is affordable in a given country is to establish the nutrient requirements of the population, the nutrient composition of the foods available and their retail cost, and then use mathematical modelling techniques to find the least cost nutrient adequate diet. This approach was taken by Chungchunlam et al. (2020) for the United States (US). Using US supermarket foods and prices, they found that the least cost daily diet that met the nutrient requirements of the average US adult had a retail cost of US$1.98. This diet contained 15 different food items, with milk, legumes and rice the greatest contributors by mass. Eggs and fish were also included in this diet.

The authors also wished to establish the least cost diet that consisted entirely of plant foods. They repeated the analysis with animal-sourced foods removed and found that the least cost diet that met the nutrient requirements of the average US adult had a retail cost of US$1.98. This diet contained 15 different food items, with milk, legumes and rice the greatest contributors by mass. Eggs and fish were also included in this diet.

Finally, the authors investigated what degree of price increase would be necessary to various animal-sourced foods before they no longer featured in the original least cost nutrient adequate diet. An 8-fold increase was necessary in the price of milk before it no longer featured, while the increases for eggs (11.5-fold), fish (6.5-fold) and meat products (3–5.5-fold) were also substantial.

While this research applies to the US, other researchers have taken a similar approach globally. Taking nationally representative food retail costs from countries around the world, Bai et al. (2021) found that the least cost nutrient adequate diet had a global average retail price of US$1.35, varying between US$1.00 and US$1.89 depending on location. However, due to the great variation in household incomes around the world, the cost of these diets was between 1% and 77% of average household expenditure. The least cost nutrient adequate diets were least affordable in regions such as Central Africa and South East Asia (Figure 1).

There was also variation in the foods included in the least cost nutrient adequate diets in different countries. In countries with lower average household incomes, meat and seafood were included in the diet, whereas these were replaced by dairy and eggs in countries with higher average incomes. This reflects the differing relative prices of these foods in different parts of the world. However, what was constant throughout the diets was a need for nutrient dense foods – in this instance, those that deliver high quantities of essential nutrients relative to energy and at a low retail price.

The availability of nutrition
Is there enough food produced by the world to feed the world? More specifically, are the nutrients required by the global population available to the global population in food?
The Sustainable Nutrition InitiativeTM at the Riddet Institute has addressed this question using the DELTA Model (Smith et al., 2021). This model captures data for global food production, distribution, waste, and end uses, coupled with food composition and nutrient bioavailability data to produce a total quantity of globally bioavailable nutrients. This is then compared to age- and gender-weighted global nutrient requirements for 29 nutrients, to establish whether global availability matches up to requirement.

The DELTA Model has found that, in 2018, sufficient macronutrients were produced globally to meet the requirements of the population. The same was not true for micronutrients, with calcium and vitamin E supply insufficient to meet global requirement. Other micronutrients, such as iron, potassium, zinc, riboflavin, vitamin A, and vitamin B12 were all less than 10% above global requirement, indicating vulnerability. These gaps will grow in size and number in the future without positive changes to the food system to ensure nutrition for all (Smith et al., 2021).

A limitation of the DELTA Model’s global perspective is that it does not capture the inequitable distribution of food and nutrients around the world. In a step towards this, the same...
A framework has been applied at a national level for the world's countries. Taking New Zealand (NZ) as an example, the model tells us that in 2015 there was sufficient macronutrient availability in NZ to meet the requirements of the NZ population. However, once again there were gaps for micronutrients. In this case, there was insufficient calcium, fibre, iron, potassium, folate and vitamins C and E available to meet requirements. This is despite the fact that NZ produces between 1.5 and 6 times the amount of all of these nutrients needed by our own population, with the exception of our low vitamin E production.

Applying this same approach to all the world's countries allows us to see the extent of inequitable nutrient distribution. Figure 2 shows that, while at the global average level almost all nutrients are available in excess of requirement, the list of nutrient gaps in individual countries is far longer. Distribution of food and nutrients should be addressed alongside increasing production.

However, the global and national perspectives above do not capture the variation in nutrient availability and consumption at the individual level. NZ nutrition survey data paint a similar picture to the national view from the DELTA Model. The last NZ adult nutrition survey found that 59% of adults had inadequate calcium intakes (particularly women), 6% had inadequate iron intakes (34% of adolescent females), and 2% had inadequate vitamin C intakes (particularly men) (University of Otago and Ministry of Health, 2011). For almost all nutrients, there were individuals found by the survey who had inadequate intakes.

These results highlight the differences between the global, national, and individual perspectives on nutrient availability and intakes. However, if there is insufficient global availability of a nutrient to meet global requirements, there cannot be sufficient availability at the national level for all countries. Similarly, if there is insufficient national availability of a nutrient, there cannot be sufficient availability for all individuals. Thus, all three perspectives are valuable and complementary.

**Conclusion**

The affordability and availability of nutrition must be a central consideration when discussing changes to global or national food systems. Research has shown that affordable nutritious diets contain diverse foods of both plant and animal origin, and that nutrient dense foods are critical. The need for nutrient density also applies to the question of availability of nutrition: nutrient dense foods (particularly micronutrient dense) are important for ensuring sufficient availability of all nutrients to a growing global and national population.

**References**


The audience were struck by the low cost of a nutrient-adequate diet in the USA reported by Dr Smith. It was asked how great a difference micronutrient fortification of individual foods had made in this work. Many of the attendees also wished to know whether the same results could be expected in New Zealand. They questioned which foods were included in the least-cost diets: were these convenience foods, or foods requiring much preparation? This will impact the acceptability of cheap diets for consumers, who are increasingly time-poor. A very pertinent question arose on the difference between nutrient-adequate and optimal or healthy diets. These are of course different, with the latter being more desirable, but likely more expensive.

The audience also asked how the prices of foods in these studies would change if full environmental costings were included. This is the difference between price and full cost, which includes environment and health, as well as any subsidies that influenced the price of the food. The group noted that it would also be interesting to see affordability of nutrition alongside local living costs, such as rent and power.

When discussing the availability of nutrients globally, the dialogue raised what the differences and barriers between nutrient availability and nutrient consumption might be. Further, what steps can be taken to distribute nutritious foods more fairly around the world? It was floated that perhaps those who get excess nutrients and can afford to eat less should do so, to free up nutrient availability for those less fortunate. There was particular interest in why calcium and vitamin E were the nutrients that showed up as deficient, rather than others (such as iron and vitamin A) that are more widely discussed. Iodine was another nutrient of interest.

The reductionist approach of the DELTA Model in analysing the food system was criticised: it presents the availability of individual nutrients from individual foods, rather than their combination into diets. It was suggested that further value could be taken from the model by including the human factors of how food is consumed.

Another interesting question was how environmental factors and costings could be integrated with nutritional data. Do nutrient deficiencies relate to soil deficiencies? Has nutrient quality in foods changed over time as a result of environmental changes?

There was some surprise at Dr Smith’s assertion of low availability of many nutrients in New Zealand. Many in the audience were very surprised that a country that produces so much calcium and vitamin C in its foods could not have enough available for its own population. Possible causes of this that were suggested included market influence and the fact that New Zealand exports such a high proportion of its food production.

Several audience tables floated the idea of reducing exports of nutrient-rich foods, to the extent that we retain enough to achieve nutrient sufficiency for our own people. The risk of not doing so is that we continue to have much of the population ‘surviving, rather than thriving.’ This is of particular concern for children in New Zealand, and data is lacking here, given that the last childhood nutrition survey was conducted in 2002.

Countering these sentiments were others who accepted that human choice is a big driver of what is exported and what is retained. If consumers are not buying something here, it drives the producers to export. Furthermore, distribution of food and nutrients in New Zealand is not equitable, partly due to individual choice, but partly due to other factors. One such factor is the lack of supermarket competition, which has a strong influence on the cost and availability of food to New Zealand consumers. Others were interested in knowing the health impacts of sub-optimal nutrition, and who in our society is bearing these costs?

In response to the talk by Prof Huppertz, the audience raised many more points relating to the discussion of nutrient bioavailability and quality. For example, discussing that the amino acid profiles of different plants differ, and that the amino acids profile of plant-based meals can be improved through identifying foods with complementary amino acid profiles. The role of amino acids beyond protein synthesis was also not covered by the speaker – these nutrients have a variety of functions and outcomes once they are absorbed, with outcomes that extend beyond nutrition to broader health.

Concern was raised that factors like bioavailability are not considered in new dietary trends, such as the rise of vegetarianism and veganism. Is the general level of nutrient quality in foods available from food banks good? Should this be a concern? Could processed foods be designed and manufactured with bioavailability and global nutrient deficiencies in mind in the future?

Some of the audience wished to clarify the bioavailability discussion. It is important to realise that bioavailability is considered when setting recommended intakes, so that comparing bioavailable quantities of nutrients to recommended intakes was not comparing apples with apples. However, this does not change the key message that bioavailability differs widely between different foods.

The audience were also interested in nutrient quality for other nutrients. Calcium and protein were the focus of the talk, and are very important nutrients, but what data exists for the bioavailability of vitamin C, for example? There are also important interactions between nutrients during digestion, such as the role of vitamin C in the absorption of non-haem iron. On a related note, what do we know about nutrient bioavailability in novel foods, such as alternative proteins? These are important factors to consider.

Professor Huppertz’ discussion of food labels also sparked much debate. Do food labels need to be longer, and show nutrient quality and bioavailability as well as composition? Just because the label says ‘contains calcium’ does not mean that this calcium is bioavailable. If we were to alter food labels, changes in bioavailability due to preparation, cooking and processing, and combinations with other foods, would also need to be considered.

The role of the consumer is important here. What changes should be made to nutrition labels to actually inform the consumer and thus achieve the purpose of the label? Adding more information could just add to consumer confusion. Further, nutrition labels are currently more widely used by wealthier or better educated individuals, who have a better understanding of the links between food and health and can afford to be more selective in their food choices. How can labelling change to better serve all consumers?

The lack of consumer knowledge on nutrition was a concern here. It was questioned why this lack of knowledge is so widespread. Is this due to education, modern food behaviours, or the globalisation of food? What can we do to improve this in New Zealand? One suggestion was using the school lunch programme. It was felt that our early exposure to food was formative for later life, and thus early nutrition education was vital.
Contemporary agricultural and dietary narratives often – and increasingly so – represent plant-derived foods as mostly beneficial whereas animal source foods are depicted as mostly harmful. Yet, both sides of this poorly informative plant/animal binary represent a very large and heterogeneous food group, of which the elements can be either benign or harmful from an ethical, environmental, and/or health perspective. It is unhelpful, therefore, to base opinion (or worse, public policy) on such simplistic categorisation. Doing so may distract from addressing some of the urgent challenges related to the production of plants (for example, with respect to water scarcity or biodiversity losses due to monoculture cropping), while unjustifiably vilifying the animal husbandry systems at the more sustainable side of the spectrum. The latter is counterproductive, as such systems not only have net benign impacts on the environment and provide ecosystem services, but they also contribute to the production of foods that (1) are rich in important nutrients (many of which are more difficult to obtain from plants and are already creating worldwide deficiencies), (2) allow for the upcycling of inedible materials and valorisation of food waste, (3) have important cultural significance, and (4) create livelihoods. That being said, the livestock sector will obviously also need to intelligently confront a wide range of problematic practices that are currently undermining the sustainability of future food systems.

Livestock as pharmakon/pharmakos

It suffices to examine the public domain to reveal that agricultural and dietary discourse is typically ridden by exaggerations and contradictions. To illustrate this, Schoenfeld and Ioannidis (2013) demonstrated through a cookbook analysis that 40 out of 50 common ingredients have been associated with either cancer protection or risk. Animal source foods, in particular, are described as both beneficial and detrimental to our health, as was shown in a mass media analysis by Leroy et al. (2018). In philosophy, something that has the potential to simultaneously heal and poison constitutes a pharmakon, an ambiguous status that under certain conditions also entails the ‘purifying’ concept of the pharmakos (scapegoat). It is of note that animals have a historical and ritualised role as scapegoats, carrying the sins of humanity. Leroy (2019) speculated that this legacy feeds into the narratives that connect livestock to a range of calamities (chronic disease, pandemics, climate change, water depletion, biodiversity collapse, etc.), despite the fact that they are also seen as valuable (in the past, but also in current food systems where they take up a crucial and irreplaceable role).

According to the latter perspective, further elaborated on by Leroy et al. (2020), livestock and animal source foods are now conceptually collapsing from the ambiguous pharmakon status into a defined pharmakos status. In other words, a transition is seen from playful ambiguity into an intimidating animal (bad) v. plants (good) binary, from which the ‘bad’ needs to be expelled (i.e., scapegoated). According to Girard (2017), scapegoats are characteristically stereotyped as monstrous and indicative of the common Other, who is proclaimed ‘guilty’ by a frenzied mob, yet is unable to retaliate. As societal insiders/outiders, animals fulfil this role to perfection. References to the monstrosities of blood and manure, planet-heating ‘cow farts’ and ‘belches’, ‘chicken periods’ (eggs), and ‘milk pus’ further underline the point. All this is indicative of conceptual tension caused by a worldview constructed on a problematic series of binaries (Life/Death, Nature/Culture, Pure/Toxic, Good/Evil, etc.), rather than on a more nuanced approach to the complexities and uncertainties of reality.

The above-mentioned observations and reflections lead to the following question: does the scapegoating of livestock serve

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Prof Leroy’s research deals with (fermented) foods, human and animal health, food studies, and ‘food traditions’. He is a member of academic non-profit societies, such as the Belgian Association of Meat Science and Technology (president), Belgian Society for Food Microbiology (secretary), and Belgian Nutrition Society. On a non-remunerated basis, he serves on the Scientific Boards of the World Farmers Organization and the Danone Institute Belgium.
as a convenient option to ignore the more challenging elements of Western consumerism, which are related to is hyperextractive production systems, while at the same time opening up an option for virtue signalling (especially in the urban centres of the West)? The challenge we are confronted with is to understand why and how scapegoating, and all hyperbole, polarisation, and hostility that come with it, is triggered.

Retracing the origins and understanding the dynamic

To understand the current animal/plant divide and pharmakon-into-pharmakos transition, a socio-historical exploration is needed. For details, we refer to Leroy (2019), Leroy et al. (2020), and Leroy and Hite (2020); the below can only serve as a sketchy and highly simplified outline for the sake of argument.

Historically, the second half of the 19th century has been pivotal. With the first 'Vegetarian Societies', founded by temperance movements in England and the USA, the idea that animal source foods corrupt human health took shape as institutionalised ideology (some historical examples of dietary asceticism and mysticism aside). By rejecting earthly life, these movements (Cowherdites, Bible Christians, and Seventh-Day Adventists, in particular) began promoting a Garden-of-Eden diet, which was connected to a romanticised interpretation of Hindu vegetarianism by Theosophists. Symbolising richness and sensuality, red meat was at odds with a world-renouncing vision of restraint, and thus portrayed as sinful compared to the blandness of 'virtuous' whole grains. As argued by Plumwood (2000), crusading vegetarians have been referring to meat eating as a morally deficient and unnecessary perversion in terms of 'corpse consumption' ever since. Even now that such religious teachings have become less relevant and are little more than a historical footnote, their lasting influence on dietary beliefs is nonetheless not to be underestimated, especially in the Anglosphere.

Due to zealous insistence within a receptive Zeitgeist, the above-mentioned Food Reformist beliefs of the late-19th and early-20th century entered the emerging field of household economics, shaping public dietary views and influencing medical discourse for decades to come (propagated by such Reformists as Sylvester Graham, John H. Kellogg, and Lenna F. Cooper). Leroy and Hite (2020) hypothesised that this may have been at the origin of what is today's healthy user bias, installing a cultural artifact in the data obtained from nutritional epidemiology in the USA, but not (or less so) in other cultural contexts. Upper-middle class Americans, who are healthier to begin with, typically eat less red meat and favour whole grains. As such, they are more susceptible to 'moral eating' and obedient adherence to dietary guidelines. This pattern is captured by observational studies which, in a positive feedback loop, further confirm and strengthen the original dietary advice underpinned by nutritional epidemiology of chronic disease. Given the low relative risks that typify such information, it is impossible to rule out (socially constructed) residual confounding and bias.

Why has a marginal dietary view, rooted in ideology, so successfully been picked up by the middle classes? Although vegetarians can be an informed and conscious personal choice based on ethical concerns or personal taste preferences, some authors such as Veit (2015) and Finn (2017) have convincingly argued that at least part of its current prevalence as a wider societal trend is due to societal unease. Loss of individual purpose in a status-oriented society mirrors resentment, amplified by what René Girard has called 'mimetic desire' (Girard, 2017).

Such a state of affairs generally parallels scapegoating and a Nietzschean 'transvaluation of values' (what was good and strong is turned into vile and sick). Whereas conventional representations of power and sensuality are demonised, victimhood and asceticism are glorified as morally superior. In the process of transvaluation, historically benign connotations of animal source foods, such as strength, abundance, sensuality, and generosity, which are particularly valid for red meat (Leroy and Praet 2015), are inverted into ones of death, infertility, debauchery, and selfishness. A sanctified state develops as one is able to refuse what was historically seen as the most nutritious foods.

Proponents of vegetarianism are frequently part of the Western middle classes, prone to status anxiety driven by an increasing wealth gap with the elites. This typically finds its expression in 'moral' eating and discourses on dietary purity, which, is also intertwined with advocacy for social causes and political activism. Usually, this is done from a 'progressive' angle, blending vegetarianism with feminism, socialism, anti-racism, etc. Yet, Buscemi (2018) has outlined in detail how it can also appeal to the ultra-right side of the political spectrum, giving expression to ecofascism. Both fractions thereby rely on an ecological rationale, in an attempt to convert those who are not convinced by the animal rights or health arguments. In any of its radical political versions, this may contribute to a developing trend of increasing ecoauthoritarianism (cf. Beeson 2010). References to a common threat, such as 'planetary catastrophe' or 'moral decline', act as a unifying narrative to shape mob homogeneity (and thus to dissolve inter-individual differences and inequalities). In both cases, dietary choice is identitarian and serves as an antidote to threatening inequality and loss of purpose.

Reinforcement of the binary by mass media in a post-truth setting

Animal husbandry and diets that are skewed to the inappropriate use of animal source foods are not without problems, but their effects on health and the planet are contextual. Unfortunately, there is little room for nuanced debate within the public space. Mass media are driven by click-bait dynamics and the so-called 'attention economy', leading to sensationalism and sweeping misrepresentations of the scientific evidence. Moreover, certain newspapers are financed by ideological and politico-economic agendas to promote one-dimensional views on the food system. Although these views are sometimes supportive of livestock farming, defending the sector's interests, they can also be hostile. Global media reporting on adverse impacts of animal source foods now overshadows the coverage of positive contributions to health, ecosystems, and livelihoods (Leroy et al. 2018; Marchmont Communications 2019).

To make matters worse, the post-truth era, and its reliance on social and mass media, has paved the way for quackery, advocacy, and manipulation of dietary discourse. Because intricacy hampers the process of societal conversion into a dietary belief system, the use of slogans is widespread. Such simplifications aim at increasing the persuasive power of the messages to be transferred. Due to the 'illusory truth effect', repetition of the same messages eventually equates with truth.

The frequent references to 'scientific authorities' further amplifies the problem, either because studies are misread or because
it is erroneously assumed that scientists are at all times rational and unbiased. Higher-educated population groups are strongly committed to an ideological viewpoint and particularly prone to ‘my-side bias’, unable to realise that they have derived their beliefs from the social groups they belong to. Often, this is also amplified by ‘white hat bias’, i.e., the distortion of information in the service of what may be perceived to be righteous ends.

**Science and scientism**

Animal source foods are now portrayed by various vocal scientists as intrinsically harmful. In contrast, healthy and sustainable eating is equated to ‘plant-based’ diets, almost by definition, while the latter of course depends on the nature of the diet rather than its plant or animal origin. Red meat is sometimes specifically labelled as an ‘unhealthy food’ together with sugar and refined grains, even by some of the leading nutritionists. This has been the case in the EAT-Lancet report (Willett et al. 2019), opposing meat’s longstanding contribution to humanity’s needs (including health) and despite the lack of solid evidence (Johnston et al. 2019). The fact that investigation of the quality of the evidence for such statements led to a vitriolic smear campaign by some of the crusading scientists involved indicates, regrettably, that the food system debate is not only about rational arguments (Rubin 2020).

The EAT-Lancet report is symptomatic: it argues for an interventionist Great Food Transformation towards a Planetary Health Diet that is essentially of a quasi-vegetarian nature, allowing only small amounts of animal source foods. Various authors have criticised the reckless use of such top-down approaches for systems in general (Gall 2012; Scott 2020), and for food systems in particular (Leroy et al. 2020). They may lead to scientism at the level of public policy making and nutritionism in the case of diets, while translating into potentially harmful policies. This is not to be considered as anodyne. In a biopolitical context, such public interventions can have serious ethical repercussions on individual responsibility and freedom, cause iatrogenic harm, and affect societal well-being. The eventual impact of a radical change in food production and eating may be devastating indeed, for nutritional security specifically, but also at a broader societal level.

**Conclusion**

There is an urgent need to acknowledge the various forms of bias that underpin the current animal/plant divide in the food system debate. Scientists are not immune, as they too operate in a society where the conditions of possibility for such mindset have been created over decades. Rather, both sides of the divide need to be scrutinised without ideological distortion so that the best of science can be applied to improve the diets of the future.

**References**


How can we feed the growing population while respecting the planet? That is the challenge we face today. We currently see an ongoing debate on whether or not it would be better for the environment if we all were to consume a vegan diet. Here, we will demonstrate that the consumption of animal source food (ASF) in high-income countries needs to be reduced, but we also acknowledge that animals could play an important role in future food systems if we were to undertake a redesign towards a circular food system. These systems can allow for reduced environmental impacts, while still providing the nutrition needed by the human population.

Avoiding feed-food competition

In a circular food system, plant-based foods are produced and processed into food for humans (Figure 1). During this processing, a portion of leftover products are produced, such as co-products or crop residues. Another leftover stream is food waste produced during food retailing, preparation and consumption. It must be our first priority to reduce the quantity of leftover streams, but if this is not possible, leftovers can be used to fertilise the soil (e.g., as compost) or to feed our farm animals (De Boer and Van Ittersum, 2018; Van Zanten et al., 2019; Muscat et al., 2021). If foods from animal sources are limited to this quantity, competition between human food and

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animal feed is avoided. In other words, arable land is no longer used to produce animal feed, producing instead only human food (Van Zanten et al., 2018). Our results showed that, in so doing, we reduce the environmental impact of the food system (Van Zanten et al., 2018).

**Feeding the animals with the leftovers from the food system**

Working with many international groups, we have been involved in assessing the potential role of animals in such circular food systems (e.g. van Zanten et al., 2018; Van Hal et al., 2019; Frehner et al., 2021). We found that it is possible to produce around one-third of the human population’s protein requirement when only feeding animals with leftover products (Van Zanten et al., 2018). However, we also found very high uncertainty in our estimates. This was largely due to the assumptions made on the food products that individuals consume. Diets in different global regions vary widely: some cultures eat largely whole grains, while others eat mostly refined grains (the same applies for rice, and for potatoes with and without peel). This has an impact on the amount of animal-sourced food that can be produced under the condition that animals can only be fed with leftover stream. In the case of refined grains, more leftovers will be available as animal feed and therefore the resulting quantity of animal products will increase.

**Circularity and health**

Whether or not someone consumes whole or refined grains not only impacts the potential amount of ASF produced in a circular food system but also impacts our health; it is, in fact, more sustainable to consume whole grain instead of refined grains. In one of our most recent studies we therefore assessed the compatibility of animal-sourced food and circularity in healthy European diets (Van Selm et al., 2021). As a starting point, we took the EAT-Lancet reference diet (Willet et al., 2019) as a prominent example of a generic diet that aims to respect human and planetary health. Willet et al. (2019), however, did not account for the opportunity cost of farm animals: the potential of animals to recycle products we cannot or do not want to eat. In Van Selm et al. (2021) we therefore assessed whether only feeding leftovers and grass resources to farm animals within the EU-28 would be compatible with the recommended ASF in the EAT-Lancet reference diet. We ascertained that it would not be possible to produce the amount of ASF that is advised in this reference diet. However, the EAT-Lancet publication also provides a reference range for food intakes, and when we aggregated food categories (for example, considering simply ‘meat’ as an aggregated group, rather than ‘poultry meat’, ‘pigmeat’, etc.) we found that it would be possible to achieve the EAT-Lancet diet under conditions of circularity. In this analysis, pork and beef constituted the majority of meat availability, with less chicken. In case the food intake ranges of the EAT-Lancet diet are not satisfied and protein production from animals is maximised while maintaining circularity, it would be possible to produce 40 g of protein per person per day from ASF (about two-thirds of the protein required on a daily basis). Both circularity diets resulted in reduced greenhouse gas emissions and arable land use compared to the EAT-Lancet diet.

An alternative to using the EAT-Lancet reference diet is to use national food-based dietary guidelines (FBDG), which take cultural differences in dietary preferences in different countries...
into account. In the study of Frehner et al. (2021), we considered the FBDG of five European countries. Translating their advice into recommended protein consumption, we found high diversity in the quantity of different proteins that are recommended. Moreover, there was substantial variability in the ratio of plant-based to animal-based proteins that were advised. Again, we considered whether the recommended amounts of animal protein could be produced under conditions of circularity. Our results showed that it was in no case possible to meet the animal protein recommendations using purely leftover products as feed.

To conclude

Our work showed that animal-sourced foods play an important role in circular food systems in the provision of essential nutrients. However, depending on the dietary requirements for animal-sourced foods, it is not always possible to deliver these while considering circularity principles. Our results showed that some animals are more efficient at upcycling leftover streams and grass resources (e.g., dairy cattle and pigs) than others (e.g., poultry). Dairy cattle as ruminants can, for example, efficiently utilise grass resources. But because dairy production systems provide milk as well as beef (e.g. from veal calves), the amount of red meat produced often exceeds the amount recommended in dietary guidelines.

Furthermore we would like to stress that the consumption of animal-sourced foods is on average too high compared to the dietary recommendations in many European countries and both the current consumption and the recommendations are higher than what could be produced when feeding animals exclusively with leftover products. On the other hand, if we apply circularity principles, we do reduce greenhouse gas emissions and arable land use, demonstrating the potential of these principles to provide important nutrients and to reduce the environmental impact of the food system. In other words, a redesign towards a circular food system offers the possibility of respecting both human and planetary health.

Acknowledgements

This conference perspective paper (Feed our Future) provides a synthesis of the work related to the role of animals in a circular food system that we have performed over recent years with many other researchers, whom we hereby want to acknowledge for their valuable contributions. This project received funding from a personal (NWO-Veni) grant to Hannah van Zanten (www.circularfoodsystems.org).

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Discussion of Associate Professor Van Zanten’s talk was dominated by the question of how circular agriculture principles would be applied in New Zealand, which has very different animal production systems compared to the Netherlands. In Europe, there is a far higher proportion of industrial, indoor-housed livestock compared to New Zealand, which has largely extensive, pastoral grazing livestock. Moreover, other parts of the world with non-Western diets will have very different livestock systems and waste streams.

Questions were raised about whether sufficient food waste and by-products are generated in New Zealand to support circularity, and how these feeds might be transported to livestock, given the large distances between densely populated regions and agricultural regions. How would transitions to these practices be applied? What incentives are there beyond reduced environmental footprint? Furthermore, what are the full outcomes of circularity on the environment, beyond the greenhouse gases discussed by the speaker?

Others were concerned about the risks of circularity done poorly, leading to biosecurity or food safety risks. There may also be negative trade-offs not touched on by the speaker, such as animal welfare impacts.

From a nutritional perspective, some in the audience were interested in the idea of considering land use from a nutrient perspective. They wished to know how nutrients moved through the circular system, from crop to people to waste and back again. Would circularity have an impact on the nutrient quality of the foods produced? It was also asked what proportions of food waste and by-products were best used for feed versus fertiliser in a circular system. Will this change in the future if we are able to reduce food waste, as we are currently striving to do?

Finally, there were comments on the use of land in New Zealand. Some asked whether we need to revisit some of our land use choices in this country, and the use of highly productive land for housing was also raised as a challenge.

Moving to the talk from Professor Leroy, many in the audience had not thought about the food system and meat from social, cultural and psychological perspectives before. One individual described the talk as ‘intense’.

Many found it very interesting to think of the food system as a cultural construct: ‘we cannot ignore the social side of food’. There was agreement that a lot of talk about extreme views exists in food systems and dietary debate, rather than consensus. Polarised debates are common, not just regarding food. There was agreement that we need to be balanced in our discussion, with less black and white statements. A plant versus animal approach to the conversation is the wrong approach. One attendee asked ‘why plant or animals, not plant and animals?’ Another wished to know whether the perception of meat in New Zealand aligned with that of Europe, or whether it was more or less extreme here.

There was agreement with Professor Leroy’s assertion that many think about eating hamburgers rather than eating animals. However, this was countered by the agreement that many New Zealand communities are still closely connected to producing food.

The delegates asked whether the disconnect between production and eating is due to less people being employed in food production, and whether the loss of family land was leaving us out of touch with the land. These phenomena also result in a loss of knowledge about nutrition and food practices, and a move away from traditional, balanced, nutritious diets. A better connection between food producers and consumers was called for.

Separately, it was also agreed that many in Western societies have become selective on what parts of the animal they will eat. However, the valuable question of how much of this discussion applies in the developing world was also raised. It is essential to also have a whole-world view that includes the perspectives of the less wealthy. Many people do not have a choice in how they get their food, and nutrition or health is not a consideration of theirs. These perspectives were not well covered in the talks.

Some in the audience wished to hear more acknowledgment of the diverse reasons that individuals have for avoiding animal foods, beyond those discussed by Professor Leroy. Dietary choice is driven by different factors for different people. These comments were made with particular emphasis on the environmental reasons for avoiding animal foods. What is the true impact of decreasing meat consumption on the environment?

Looking to the future, one attendee asked what the next phase in the social perception of meat consumption might be. This is tied into the discussion in the room about communication and recent media drives to extreme perspectives. How do we regain the narrative in the post-truth world? What is the role of the media and social media in informing the public on challenging issues like meat production and consumption? Are they partially to blame for drumming up extreme views with simplified messages? A similar notion is the idea of extremes around organic versus conventional, or fat-free versus full-fat.

The delegates were again in agreement that simplified messages about non-extreme views are needed. Some were concerned that it may be too late to change the minds of younger generations. One attendee was worried that extreme messaging was driving more children to adopt vegetarian or vegan diets, with dire consequences for their nutrition and development. All of this emphasised the importance of being reminded about the degree to which human values impact on our discussions about food. This point is critical, as having effective conversations is essential if we are to make progress on ‘feeding our future’. Many in the audience wished to hear what possible solutions to the currently divisive debate might be.

The current role of meat was questioned by the audience. It was noted that much of the debate thus far had centred on protein, but there are other important elements to good nutrition, such as fibre, that need to be considered. We in New Zealand have always assumed that the wealthier consumer will always demand meat and dairy – but is this true? One asserted that we put a lot of effort and money into protecting and defending the status quo, rather than embracing innovation.

Overall, there was agreement that effort should be focussed on solutions, rather than just the causes of the challenges. Sustainable diets will be part of the solution, and these need to be culturally acceptable, as diet plays a key part in identity. The true problems to be tackled from a nutrition and health perspective are overconsumption, particularly of highly processed foods.

*Discussion summaries were collated by Dr Nick Smith, based on written notes collected from the tables in the room and video recordings of the facilitated discussion sessions on the day.
A generation has passed since the publication of Our Common Future, known as the Brundtland Report, which set out a requirement for sustainable development indicators so that policy makers could quantify the total value of all natural resources (Brundtland, 1987). This began a process of providing the global food system with a set of values that would provide baseline information or starting points for which future indicators and assessments of sustainable development could be made. It has provided sustainability route maps and recognised that new data tools were needed to implement solutions for sustainable development. The food systems role in achieving this was of importance because of the data held in supply chains concerned with the energy and materials used to manufacture and distribute food. An example of such a primary impact indicator is the use of nitrogen fertilisers that support high-yielding agriculture; their role in the food system is critical, with over a fifth of the nitrogen in all global protein being derived from industrially manufactured nitrogenous fertiliser (Smil, 2002). There are important outcomes for the use of energy and materials, such as the release of nitrous oxide greenhouse gases from organic and mineral nitrogen fertiliser use, that are identified as causal agents in environmental change. Characterising these materials and their associated processes has brought forward new methods of assessing nutrient flow, and the use of digital technologies has enabled improved traceability of information regarding their use. This has enabled the use of common frameworks and vocabularies to describe sustainable practices, which helps to provide incisive models, scenario generation and digital twins for food system activities.

One of the most recognisable of these common frameworks and vocabularies for industry and consumers in the food system is the value of nutrients whose production and consumption determines their impact on human nutrition. It has transformed not only how compliance and verification of foods is achieved with standards and certifications, but also how nutrient content is communicated through the labelling of products. There are important differences between nutrient content, which regulators can quantify on labels, and nutrition, which is far more complex to define and requires further consideration. The DELTA Model and the Sustainable Nutrition Initiative have both started to test the connection between nutrient content, nutrient availability and national nutritional requirements (Smith et al., 2021). It is the loss of nutrients through inefficient operational practices and food waste behaviours that will be built into such tools because each has important impacts on nutrient availability and it is reported that up to a third of food produced is wasted (Chen et al., 2020). Nutrient loss and food waste must first be quantified so that meaningful food policy can be developed so that models such as DELTA can perform robustly enough to account for variations in waste between nations and different food groups or categories.

The relationship between supply chain nutrient losses and food waste is not straightforward, because the economic and nutritional value of different food categories varies. For example, the FAOStat Producer Price Index (typically the wholesale price) for New Zealand beef (deadweight, $USD 3247 per tonne in 2015) is lower than that of UK strawberries ($USD 3973 per tonne in 2015) even though their nutritional values are wildly different and their sustainability impacts have even less of a resemblance to each other. It is noteworthy at this point to consider that much environmental dialogue citing Life Cycle Assessment (LCA) data will still continue to compare the impact of plants and animal products without considering economic or consumer value. The strawberries and beef scenario indicates how tangled advice can get and it is further compounded by production systems between nations being very different because of available resources. New Zealand Producer Prices for beef,

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lamb, pork and, of course, whole milk are typically at least a third lower than in the UK, which is in large part due to geographic resources available. The complexity of assessing sustainability is clear and any assessment needs to consider how consumers value different food categories, because this certainly has impact with foods that are more expensive and preserved, which are rarely wasted (Martindale, 2016).

Improved accessibility to foods can provide a system of being able to afford to waste and eating more of what is enjoyable so that poor dietary choices can be made more often. The results are evident in the descriptive literature, where food waste is more prevalent in high-income countries, as are diseases such as diabetes and coronary heart disease (Swinburn et al., 2015). Food wastage is stifling efforts for developing a sustainable food system, because even if sustainability is achieved at least 20% of food products are currently wasted during preparation and consumption (Caldeira et al., 2021). What is the point of certificating products for sustainability if they are wasted? The issues of fair global access to food and the inequality of resource distribution in the global food system must be tackled if international policy frameworks such as the Sustainable Development Goals (SDGs) are to be met. One of the most visible demonstrations of this inequality is shown in Figure 1, where the number of Calories wasted per person per day for different nations globally shows high-income nations waste more nutrients than low- or middle-income countries. There are similar relationships for most nutrients; their loss is greatest in those nations that have access to nutrients and can afford to waste them. High-income countries waste 33 daily diets per person per year whereas low- and middle-income countries waste 4 daily diets per person per year (using the supplementary data of Chen et al., 2020). If sustainable outcomes are met, the global food system cannot seek to bring all citizens up to this level of high-income wastage, and there needs to be a re-thinking of policy and action that brings waste to a level where there is greater equality. Figure 1 demonstrates a universal principle that is often seen in sustainability research: failure is a result of resources being distributed on unequal terms through geography, income, or culture that creates inequality, and each must be tackled systemically.

Research demonstrates that food waste can be reduced to zero for each meal if preservation and cooking preparation are considered in achieving sustainable outcomes, with product development having an important role in delivering this (Martindale, 2016). Manufacturers are now reporting carbon zero product categories including whole milk and beef, where such improved understanding of how resources flow through food systems has made such baseline or zero targets a reality. Research developed at the National Centre for Food Manufacturing in the UK has provided an important start to reporting how a Digital Twin for Consumption (DTC) can be used to assess the utilisation of resources in food supply chains. The methodologies are being developed by co-creating delivery across Geographic Information Systems (GISs), LCAs, and demographic data science. The data shown in Table 1, are typical of the DTC projections for GHG emission and waste data for different diets when they are scaled to the UK population. It shows a greenhouse gas (GHG) emission and waste production scenario for the typical National Dietary and Nutrition Survey (NDNS) diet reported by the UK Government against the Live Well diet which generally provides a 10% reduction in livestock product consumption. The data reported by the DTC is compared to reported UK Office of National Statistics data including UK’s 6th Carbon budget; Wrap’s Food Waste Trends 2019; and UK’s Family Food survey 2018/19. The DTC tests provide robust alignment between modelled data outcomes and actual reported data so that further analysis using the DTC methodology can be carried out with confidence.

Figure 1. The number of Calories lost and wasted from diets globally. 40% of the Recommended Daily Amount of Calories are lost (as much as 710 Calories) using the supplementary data of Chen et al., 2020.
Table 1 shows that the DTC will provide robust projections of GHG emissions, waste production and expenditure based on population demographics reported by the UK National Census. The use of the DTC is being tested because the UK 6th Carbon Budget identifies some 60% of the currently achievable 20 million tonnes of GHG emission reduction from the UK agri-food system each year will be achieved through dietary change and reducing food waste. This means a change from livestock to plant proteins is not the only answer in achieving GHG emission targets, because such a transition will result in more food waste due to more fresh produce being wasted than livestock products (Table 1). The DTC demonstrates how sustainable dietary policy can be structured for the most realistic outcomes that consider eating behaviours and the agility of food choices made by consumers. Mapping how resources and nutrients move through supply chains is of use to reporting the risk of waste or losses, this has been tested and it will be developed further to include the impact of eating behaviours and choices (Martindale et al., 2020). The DTC and other risk models improve on those that use static ‘peak resource’ limits without considering innovation in product development, changes to manufacturing technologies, or the variance in consumer choices. These are important considerations, since changes in manufacturing and processing technologies will often reduce energy consumption and can improve product quality. This has been demonstrated at NCFM most recently with advanced steam infusion processing for soups, confectionery and dairy products (Brooks et al., 2021). The use of preservation techniques such as freezing and drying with storage interventions such as the use of fit-for-purpose packaging have also been shown to result in less food waste. Peak resource models can identify boundaries where technologies such as steam infusion can have greatest impact, but models need to be agile and construct future scenarios, and this is where digital twins become a more realistic option in providing risk reduction strategies.

Meeting sustainability and nutritional goals must also result in food being affordable, available, and assured, so New Product Development (NPD) strategy must take a concept-to-consumer approach for this to happen (Martindale, 2016). It is this insight that will provide total utilisation of foods by consumers and connect the sustainability attributes of nutritional improvement and waste reduction which are universally desirable impacts across supply chains. The impact that these GHG and waste reduction models have on NPD processes has also been tested for the UK food system with the DTC, and the research indicates that similar approaches to food and beverage NPD could be utilised in the food system for global impact.

Table 1. A Digital Twin for Consumption (DTC) demonstrator providing data on the relationship between dietary consumption, GHG emissions, and food waste. The DTC is developed by the author and reported by Martindale and Lucas (in press, Springer Nature 2021).

<table>
<thead>
<tr>
<th>Digital Twin projection</th>
<th>ONS data</th>
</tr>
</thead>
<tbody>
<tr>
<td>(modelled data)</td>
<td>(reported data)</td>
</tr>
<tr>
<td>GHG emissions livewell diet (x 10^6 tonnes. yr^-1)</td>
<td>52.5</td>
</tr>
<tr>
<td>GHG emissions NDNS diet (x 10^6 tonnes. yr^-1)</td>
<td>54.9</td>
</tr>
<tr>
<td>Domestic food waste livewell diet (x 10^6 tonnes. yr^-1)</td>
<td>9.4</td>
</tr>
<tr>
<td>Domestic waste NDNS diet (x 10^6 tonnes. yr^-1)</td>
<td>7.1</td>
</tr>
<tr>
<td>Consumer retail expenditure groceries (x 10^9 GBP. yr^-1)</td>
<td>144.4</td>
</tr>
</tbody>
</table>

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Agriculture and food have a major impact on the global environment, as shown in Figure 1. Food production contributes over one-quarter of the global greenhouse gas emissions, uses about half of the habitable land, and around 70% of all freshwater withdrawals, while contributing to over 75% of the pollution of our oceans and freshwaters. Therefore, when we discuss food and the efficiency of its production, it is essential that we consider the environmental impacts.

The commonly used approach to assess the environmental impacts of food is Life Cycle Assessment (LCA). With this approach, we attempt to account for all life stages of a food that contribute to environmental impacts. This goes beyond the farm, also considering processing, shipping, consumer use, and waste.

**Implications of nutritional indicators**
When we report values for an environmental impact, we must represent these in terms of a functional unit. But what is the function of a specific food? This question is extremely important, as most of the existing data is simply presented on a weight basis. A huge amount of work has been undertaken around the globe to calculate the carbon footprint of foods, but these results are almost always expressed per kilogram.

However, the value of food is more intricate than just its weight. The moisture content and the nutritional content of foods vary greatly. In most studies where carbon footprints are expressed per unit of mass, animal-sourced foods tend to have much larger footprints than fruit and vegetables. While the variability in footprints between different production systems is great, the general trend remains.

It is important that our analyses of environmental footprints go beyond simple comparisons with mass as the functional unit. Firstly, consider the food energy perspective. Figure 2 shows livestock products at the higher end and fruit and vegetables at the lower end on a mass basis. However, we see quite a different pattern when this data is expressed per calorie, with fruit and vegetables having the highest footprint per calorie.

We can also consider protein. The importance of protein as a component of the diet has been discussed by previous speakers, and Figure 3 shows a comparison between using a mass functional unit and using protein. In this instance, apples have a high impact per unit of protein, but low impact per unit mass. Clearly, the protein content of apples is not the quality that we look for in this food, and as such, comparing apples with livestock products on a protein basis is not necessarily reflective of...
the value of these foods. However, it emphasises the need to compare the environmental impact of foods on a fair basis, reflective of the function of that food.

What must also be considered is the method of production of food. For example, tomatoes grown in a heated greenhouse require high energy inputs for heating and light to meet out-of-season demand, resulting in a far higher carbon footprint than conventionally grown tomatoes (Figure 3).

Other speakers have emphasised that protein is not the whole picture, and that we need to be thinking about the essential amino acids also. A meta-analysis of different food types by Tessari et al. (2016) showed that livestock products have a high carbon footprint per unit mass. However, when the data is presented in terms of the mass required to meet the recommended daily intake of all essential amino acids, a different picture was presented (Figure 4). In this instance, rice and cauliflower have the highest footprints, further emphasising the importance of the value by which we compare food items.

The question now becomes how to unify these approaches and find a best practice approach. A number of researchers have attempted to use multiple nutrients together as the functional unit (e.g. Fulgoni et al., 2009; Sonesson et al., 2019). In recent years, a further shift has been seen, comparing foods on a whole diet basis (e.g. McAuliffe et al., 2020). This recognises the need to have a balanced diet. However, there is very little agreement on the best method by which to do so.

To focus on New Zealand, we are fortunate that in the last year, there was a publication that brought together data on the carbon footprint of New Zealand diets (Barnsley et al., 2021). The average New Zealand diet was compared to a diet that followed the Ministry of Health dietary guidelines (Ministry of Health, 2020) that featured more vegetables and whole grains but still contained a mix of other components. The authors also considered a no-meat diet. The diet that shifted to the recommended dietary guidelines showed a 7–9% reduction in global warming contribution over the lifetime of an individual, while the no-meat diet showed a reduction of 12–15%. Importantly, the authors noted that the no-meat diet had inadequate iron, lower protein, and higher sugar content than the diet following the guidelines.

How do New Zealand products compare with those from overseas countries?

Research on New Zealand livestock products has shown the relatively low carbon footprint of our production systems. The results in Figure 5 show the on-farm carbon footprint of milk around the world. These results refer to the cradle-to-farm-gate stage and do not account for the full life cycle of the product, but research has shown that the on-farm stage is the dominant contributor for livestock products, including milk (e.g. Thoma et al., 2013). New Zealand milk production is at the bottom end of the range globally, as is our beef and sheep meat production (Figure 6). This reflects the fact...
that our systems are based on a pasture diet with year-round grazing of very-high quality pasture compared to many northern hemisphere systems with animal housing (e.g. Ledgard, 2017; Lorenz et al., 2019).

Looking to the future of New Zealand land use, I am certain that over the next fifty years we will see increased diversity. We already see this starting to happen with larger and more diverse quantities of crops, vegetables, and fruit varieties in particular. However, in thinking about these changes, we must consider land use suitability for these different applications. There is a limited land area in New Zealand that is highly suitable for crop production. Over the last few decades, we have occasionally tried to introduce wheat production in the Waikato region. However, on each occasion, these attempts have come to nothing due to disease problems. Other factors limit our ability to grow many crops in many parts of the country, including soil characteristics (heavy-textured, poor-draining soils), land slope, high rainfall, and humidity. In these situations, the production of animal feed and pasture can be an optimal use of the land for food production. However, there will always be a balance in the foods that we should produce, which will shift through time.

Environmental labelling of products
In the last 10 years, the European Commission have been putting a lot of focus into working on product environmental footprints (PEFs) for labelling food on supermarket shelves throughout Europe (European Commission PEF, 2021). This move relies on a lot of science, some of which New Zealand has been involved with. It is important that, rather than just reporting a single indicator for environmental performance, the multiple environmental impacts of a product are captured by these initiatives, and the PEF initiative covers up to 16 different resource use and environmental impact categories.

To focus on a few of these, fossil energy depletion is emerging as an important measure. New Zealand looks good on this basis due to our largely grazed animal production systems, compared to a system where crops are harvested and transported to the animals. Another measure is the pollution of fresh waters and the ocean. This may be something of an Achilles heel for New Zealand, but there are no published summaries of data for this measure in the same way as those we have seen for carbon footprinting. This is partly because there has been a lack of agreement on how to quantify water pollution impacts using LCA, but clearly this is an area that we need more focus on in the future.
to understand whether we are in fact worse than some of our overseas counterparts with housed livestock systems.

Perhaps more pertinent globally is the issue of a water scarcity footprint. While greenhouse gases are a global issue, since gases emitted have an equal impact regardless of where they are emitted, water dynamics are more localised. Billions of dollars are spent moving freshwater from areas of abundance to dry, arid areas such as in north-eastern China or California. When we consider freshwater use, we need to understand the demand for it relative to its local availability. In this instance, there is an internationally accepted approach called a water scarcity footprint. An element of this footprint is the water stress index (Figure 7).

To summarise, we will see more environmental labelling of foods in the future. This will feed back to us in terms of driving more efficient production in the future and the need to reduce greenhouse gas emissions in our production systems. However, it is important that New Zealand is involved at a global level in making the consumer aware of how to interpret these footprints. The per-kilogram footprints presented in many papers are not the whole picture; we should also consider the nutritional element of these footprints and the implications for diets that meet our nutrient requirements.

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Discussion Session 3 – Food systems impact

Associate Professor Martindale’s highlighting of the positive correlation between health and food waste interested the audience. In particular, seeing food waste through the new lens of the quantities of nutrients wasted was striking. There was also some questioning of why food waste is still such an issue, given that it is not a new concept.

One attendee stated that we do not have a culture of worrying much about waste, and a lot of our food waste decisions will not be consciously made. We often purchase more food than we need in this country, heightening the risk of waste. Overconsumption is another form of food waste that is prolific in New Zealand.

There was interest in whether the figures stated for food waste in the UK would also apply to New Zealand. What are the main foods wasted in this country and why? Is our food waste increasing or decreasing over time? What happens to food once wasted? Further, where in the supply chain does the most food waste occur: production, transport, retail, or the consumer? It was suggested that the removal of ‘best before’ labels and retention of ‘use by’ dates is one way that retail can address consumer food waste.

It was suggested that our high-quality food export economy also contributes to waste, for example through the grading of fruit. One attendee asked whether local food production reduces waste, while another was interested in the impacts of food processing on food waste.

In answer to Professor Martindale’s assertion that wealthier countries can afford to waste food, one attendee asked what the true cost of this waste is, and whether it would still be considered affordable with full economic, environmental and social costing taken into account.

It was noted that Australia is focussing on food waste using a systems approach, but it was not apparent whether New Zealand was doing the same. It was acknowledged that New Zealand is very good at redistributing unused or unsold food to those who need it, largely through non-profit organisations. A suggestion for addressing food waste with a more holistic approach was the use of block-chain tracking technology, which captures the nutrient density of food, their environmental credentials and identifies opportunities to redistribute the right foods to the places they are most needed. The impressive modelling and scientific capabilities now available should be leveraged to better inform producers and consumers on the impacts of their choices.

From a consumer perspective, many attendees wanted to know more about how we might reduce consumer food waste in a way that would be accepted. Is more data the answer to addressing overconsumption and consumer behaviour, or education? There was some debate as to whether waste reduction can be successfully addressed by the consumer, or whether top-down approaches are necessary.

Final comments included the link between Professor Martindale’s talk and Professor Van Zanten’s: the role of food waste in the Discussion Session 3 – Food systems impact. It was acknowledged that New Zealand is very good at redistributing unused or unsold food to those who need it, largely through non-profit organisations. A suggestion for addressing food waste with a more holistic approach was the use of block-chain tracking technology, which captures the nutrient density of food, their environmental credentials and identifies opportunities to redistribute the right foods to the places they are most needed. The impressive modelling and scientific capabilities now available should be leveraged to better inform producers and consumers on the impacts of their choices.

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Final comments included the link between Professor Martindale’s talk and Professor Van Zanten’s: the role of food waste in circular agriculture is clear. One attendee asked: which is the bigger problem, waste or affordability of good nutrition? Should our attention be prioritised as such?

Dr Ledgard’s talk made it clear to the audience, as shown in the discussion, that environmental footprinting of foods is a challenging topic. Different methodologies, terminologies and definitions abound, and clarity on these really matters for the understanding of the non-expert.

Dr Ledgard presented a number of metrics and ways of examining life-cycle analysis data, leaving the audience asking which metric should be used. Should we consider production or consumption footprints? What functional unit should be used for different food products? The use of protein as the functional unit makes sense for meat or beans, but not for tomatoes, as demonstrated by the speaker.

Where are the correct boundaries for an assessment? Does the environmental impact of food produced in New Zealand but consumed in Europe need to be attributed here or there? How much of the on-farm activity and its environmental impact can be attributed to a food product? What are the differences in conclusions when we consider the impact of national production averages versus local production impacts? Ultimately, if we can’t agree on the correct metrics to use, then it will be very hard to agree on the costs and benefits of proposed changes in the future.

Other attendees emphasised the need to consider the footprints of diets, not just individual foods. Another important inclusion was food processing, and packaging, each of which has its own footprint.

There are many environmental impacts of the food system, and while Dr Ledgard covered several, there are more, such as biodiversity loss. Most of the existing impact data is from Europe and developed countries – what would happen if we had a clearer idea of the footprints from the rest of the world?

The audience appreciated the presentation of impact data in new and interesting ways, particularly by using different functional units. Some thought it would be interesting to see these data with bioavailability and nutrient quality included. Others believed that would be taking the analysis further than would be useful.

Environmental labelling of food products was discussed at length by the delegates and agreed to be fraught with challenges. The speaker showed that there is much information that could be conveyed. However, inconsistencies or inaccuracies could lead to misinformation for the consumer, and too much information would quickly become overwhelming. For example, how will a consumer differentiate between a ‘carbon zero’ claim being achieved via offsetting versus one achieved by addressing carbon emissions on farm? Any labelling that is introduced would need to be readily understandable, and locally relevant.

Overall, there was an agreed need to approach the environmental question from both a short-term and long-term perspective: what will be the impact of an activity this year, in ten years, and in centuries to come? There was also the challenge in New Zealand of our great vested interest in agriculture, which can cloud the analysis of environmental impacts. The footprint of New Zealand agricultural products is very good in comparison to the rest of the world, but we cannot aim to simply be ‘the best of the worst’.

*Discussion summaries were collated by Dr Nick Smith, based on written notes collected from the tables in the room and video recordings of the facilitated discussion sessions on the day.
As consumers become more concerned about the impacts of their food choices on both their own health and the health of the planet, the need for innovative methods to produce foods that are not only nutritious but environmentally friendly and ethical is rising more than ever before. Alternative ways of supplying proteins into human diet have been one of the most controversial subjects over recent years, resulting in development of various methods to replace conventional animal-based products, such as milk and meat. With recent advancements integrating cell-culture, genetic engineering, and food science, producing meat or milk in a laboratory is no longer only a scene in science fiction movies.

According to the United Nations’ World Population Prospects (UN, 2019), the world population will grow from 7.7 billion people in 2019 to 10.9 billion in 2100, with the countries of Sub-Saharan Africa accounting for more than 50% of the global population growth (Figure 1; Wood, 2019). Therefore, feeding a growing world population must first and foremost consider people living in those rapidly growing regions and not just Europe or the USA where population is projected to begin to decline before the end of this century. That said, are the current innovations in producing food for a growing population, such as lab-grown meats, ultra-processed plant-based products, precision fermentation and insect proteins applicable to the countries where food security and malnourishment are still major issues? We need solutions that work for these developing countries and their people not just middle-class Western consumers.

The changing face of protein production

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As consumers become more concerned about the impacts of their food choices on both their own health and the health of the planet, the need for innovative methods to produce foods that are not only nutritious but environmentally friendly and ethical is rising more than ever before. Alternative ways of supplying proteins into human diet have been one of the most controversial subjects over recent years, resulting in development of various methods to replace conventional animal-based products, such as milk and meat. With recent advancements integrating cell-culture, genetic engineering, and food science, producing meat or milk in a laboratory is no longer only a scene in science fiction movies.

According to the United Nations’ World Population Prospects (UN, 2019), the world population will grow from 7.7 billion people in 2019 to 10.9 billion in 2100, with the countries of Sub-Saharan Africa accounting for more than 50% of the global population growth (Figure 1; Wood, 2019). Therefore, feeding a growing world population must first and foremost consider people living in those rapidly growing regions and not just Europe or the USA where population is projected to begin to decline before the end of this century. That said, are the current innovations in producing food for a growing population, such as lab-grown meats, ultra-processed plant-based products, precision fermentation and insect proteins applicable to the countries where food security and malnourishment are still major issues? We need solutions that work for these developing countries and their people not just middle-class Western consumers.

The alternative protein challenge

Plant-based products for instance, such as plant milk replicates or plant-based fake meat, have gained considerable popularity over the past few years. Despite their nutritional value and environmental footprint being constantly scrutinised, it is predicted that the market size for these products in Australia alone will be $3.1 billion by 2030 (Admassu et al., 2020). These products will not be the focus of this article; instead, we will discuss the less debated area of recombinant food proteins (precision fermentation), cell-based meat, and insect proteins.

One industry report speculates that: the cost of (recombinant) food proteins will be five times cheaper by 2030 and 10 times cheaper by 2035. By 2030, modern food production will be higher quality and cost less than half as much to produce as changing the food system?

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Prof Wood brought a number of innovative products to the market, receiving recognition for his work to invent a new diagnostic test for tuberculosis, including the CSIRO Medal, the Clunies Ross award and being made an Officer in the Order of Australia. He is the Chair of the Global Alliance for Livestock Veterinary Medicines, on the Board of Dairy Australia, and currently is an Adjunct Professor at Monash University and a Fellow of the Australian Academy of Technological Sciences and Engineering.

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animal-derived products. By 2030, the number of cows in the USA will have fallen by 50% and the cattle farming industry will be all but bankrupt. The whole of the cow milk industry will collapse once these technologies are used to produce the individual proteins in milk and this industry will be bankrupt by 2030 (Tubb and Seba, 2021). These predictions are based solely on their view of advances in precision fermentation.

**Precision fermentation (recombinant protein production)**

Precision fermentation is ‘a process that allows us to program micro-organisms to produce almost any complex organic molecule’ (Tubb and Seba, 2021). In other words, we take the gene for a protein (say beta-lactoglobulin) that we want to produce and insert it into a plasmid and then transfect that plasmid into a cell that can produce this protein in a fermentation vessel (Figure 2). It all sounds fairly simple and today it is, but it is not cheap to do.

Figure 2. Processes involved in producing recombinant protein through precision fermentation. [Created through BioRender.com]

For example, how would we produce one billion litres of precision fermented milk using yeast cells? There are six key proteins in milk, and we would need to ferment each one separately, as each gene construct will perform differently in the laboratory. For milk with 3% protein content, we would need 30 million kilograms of protein. With yeast cultures producing around 10 grams of recombinant protein/litre that would require three billion litres of yeast culture media. Using 10,000 litre fermenters, we therefore require approximately 12,000 10-kilolitre bioreactors. If we assume that a production run takes two weeks, involving a set up phase, fermentation step and clean-up and re-sterilisation process, that would allow for 26 production runs each year. This would require $600 million in the cost of the fermentation equipment alone, not including staff, facilities, or materials.

Currently production costs for the many recombinant proteins used in medicine are hundreds of thousands of dollars per kilogram but a lot less for industrial-grade proteins like cellulase and beta-glucosidase, used in ethanol production (Puetz and Wurm, 2019). The major reasons for these large differences are the regulatory standards required and the extent of downstream processing needed to produce a highly pure and consistent final product. Assuming an estimated final cost of around $100/kg for the recombinant milk proteins, that would result in a cost of goods of $3/litre for protein alone in the final product. We would then need to add sterile water, fats, sugars, minerals, and vitamins to produce the final precision fermented milk. The last step would be some form of filtration or sterilisation before bottling the final product. Our estimate is that the likely cost of production of these products would be at least four times that of fresh milk. There are companies like Perfect Day already producing ice-cream with recombinant beta-lactoglobulin in limited amounts.

In an effort to revolutionise the infant nutrition industry, a Singapore-based startup, TurtleTree Labs, is producing human breastmilk by culturing mammalian cells in the lab. Although still in its infancy, the company has raised $3.2 million seed funding and managed to get closer to an economically viable price range by reducing their cultured milk price from $180 per litre to $30 per litre. Again, is this a solution for solving the food shortage issues outside the Western world?

**Cell-based meat**

Many high-tech companies are now shifting their focus to producing cell-based meat (e.g. Memphis Meats, Eat Just), also known as cultivated, *in vitro*, and cultured meat, referring to ‘meat cells cultivated in cell culture bioreactors, as opposed to on a farm’ (Vergeer et al., 2021). A lot of the processes for production of cell-based meats will be the same as precision fermentation as explained above, except that you grow muscle cells from a cow in the same types of fermenters. However, mammalian cells are far more expensive to grow than yeast because they need special growth factors and nutrients. These essential cell-growth factors, such as insulin growth factor, will be produced as recombinant proteins as described above. In a recent report commissioned by the Good Food Institute, an estimated costing for cell-based meats was modelled for production of 10 kilotons of cell-based meat per year (Vergeer et al., 2021). Their best estimate, which assumes some significant improvements in the final cost of media and facilities, was $133/kg. With ground beef at less than $5 per kilo there is a major challenge ahead. Their estimate for the cost of a cell-based meat production facility was US$450 million and 1000 of these facilities will be needed to replace the current beef production in the USA alone. In addition, all energy would need to be from fully renewable sources to be more sustainable than current meat production systems (Lynch and Pierrehumbert, 2019). The same group also discussed some possibilities to reduce the cost of producing cell-based meat by 2030 in order to bring it closer to a commercially viable alternative. These possibilities include: lowering the price of growth factors and recombinant proteins, increasing cell density, shortening production run time, and using larger cell volume, hence increasing production efficiency and minimising media, equipment and energy use. They estimated that by reducing the price of recombinant proteins and growth factors only, the production cost could potentially drop to $15/kg, whereas implementing all of the above-mentioned strategies for lowering costs will potentially reduce production costs to a price that is comparable to the traditional meat value ($2/kg).

In summary the estimates for cell-based meat production are currently 100- to 1000-fold that of conventional systems. Their major problem is that they assume that a cell-based facility can be run at a food-grade standard when in fact it will have to be a pharmaceutical-grade standard (see Figure 3).
In the USA, the Food and Drug Administration will regulate the fermentation process and the US Department of Agriculture the production of the final products, further complicating what could be a difficult regulatory environment (Watson, 2019). The growth cycle for a batch of cells will be a minimum of 42 days of continuous sterile culture, almost impossible to maintain without rigorous manufacturing standards. The optimism that cell-based protein costs of production can be decreased by over 1000-fold are unrealistic, given that after tens of billions of dollars of investment by the pharmaceutical industry over the last 20 years, the productivity of cell-based medicinal products was only improved by 10- to 20-fold. In essence, cell-based meats at best will be a high-value niche product servicing middle- to high-income consumers. The final product is also just a burger, not a prime steak, that will require a whole new set of technologies such as edible cell scaffolds and 3D printing of meat.

**Insect proteins**

Food waste is a significant problem, with over 30% of the food currently produced being wasted. Using insects such as soldier fly larvae and mealworms we can convert these waste streams into highly nutritious protein for pets, fish, and livestock. Over $600 million Euros have been invested and several facilities are already farming insects at large scale (6,000 tonnes per year) with Protix in Europe and Enterra in Canada (Niyonsaba et al., 2021). Numerous insects are also already consumed whole by humans, with two billion people in 130 countries enjoying these products, and there is no reason in the long run why insect proteins, when produced in powdered form, cannot be used for human food manufacture.

**Conclusion**

All of these new technologies are technically viable. The challenge is whether they can be manufactured at scale and a cost of goods to be commercially viable. It is unlikely that these new protein sources will replace animal-sourced proteins, and there are significant questions about their environmental and nutritional claims. There are already restrictions in various countries on the use of terms like ‘milk’ and ‘meat’ on food labels for these alternative protein products, such as plant-based milk, and this could also be a problem for precision fermented and cell-based products. There are also challenges with consumer acceptance of products that will be produced with genetically modified organisms, cell-based culture systems, or insect farming. In most cases they will be niche products for high-value markets for consumers in developed countries.

**References**


Introduction

The EAT-Lancet report highlights that by 2050 a substantial dietary shift is required to ensure a healthy and sustainable future food supply (Willett et al., 2019). There is much debate about the changes needed to achieve these sustainable diets, and indeed what foods are more sustainable. The consumer is said to be demanding more sustainable foods and, increasingly, they are presented with new foods, new diets, and alternative products to those they are used to. Nevertheless, mass consumer acceptance of these products should not be assumed (Bauer & Reisch, 2019).

The general opinion is that, although challenging, at a global level it is theoretically possible to develop the technology and capability to produce the food needed for a sustainable nutritious diet (Willett et al., 2019). However – and here is the drawback – there will not be a shift if the consumer does not engage with the new farming systems, processing technologies and new foods, and habitually adopt them in their diet. The relationship between an individual or community and their food is very emotive and very complex (Delind, 2006), and so, if sustainable nutritional diets are to be attained, the consumer factor must be acknowledged and integrated into new food system solutions.

Liking v. wanting

People are at the centre of our food systems, and hence influencing consumer behaviour and the food contexts in which those behaviors take place is a central route to dietary change. To engage consumers with new foods, and hence shift their diet, they have to want them – not just like them, but truly want them. Liking and wanting are processed differently in the brain, and it is wanting that controls human decision making and behaviours (Berridge, 2018). Take a quick look at market trends, social media, menus in restaurants, or even asking consumers what they would like in terms of new foods, and it appears they have already made the transition to plant-based diets in droves. However, the claims made by the consumer about what they want, and why they want it, do not always translate into behaviours. This is known as a value-action gap (Blake, 1999) and it can hinder and delay dietary shifts and behaviours.

To that end, all stakeholders need to have a better understanding of what the consumers want – really want. It is known that taking a consumer-led approach, rather than simply a market- or technological-led approach, often leads to more habitual uptake of products (Horvat et al., 2019). For example, Heinz are well-known for the observational consumer-led approach, which resulted in the upside-down squeezy bottle that was much more effective at delivering ketchup (Jewell, 2018). Famously, Steve Jobs commented that ‘the consumer doesn’t always know what they want until you show it to them’ (Isaacson, 2011), and that can be true, but there are new ways of understanding those needs, for example, ethnography and consumer co-design activities to provide a better picture of consumers’ true wants/needs and pain points (Ares & Varela, 2018) which can help grow and develop products that deliver to the consumer in terms of the products themselves, as well as their nutrition and sustainability credentials.

Consumer drivers

What do consumers actually want where future foods are concerned? Research tells us, and it should be no surprise here, that price is a key driver of product engagement, alongside the need for human gratification, that is the food’s sensory appeal (Glanz et al., 1998). Human beings are specifically designed to get a rewarding experience from food and reject it if it isn’t. The foods that consumers choose need to be rewarding in some way to be adopted, both in terms of the sensory experience and other extrinsic rewards that matter to that particular consumer (Köster, 2009).

Changing the food system?

Consumers are central to any change in the food system

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Joanne Hort took up the position of Fonterra-Riddet Chair of Consumer and Sensory Science at Massey University (NZ) in July 2017, moving after 15 years at the University of Nottingham (UK) where she was latterly SABMiller Chair of Sensory Science. Her research focuses on a multidisciplinary approach to understanding the factors effecting consumer perception of food and beverages and consequent choice behaviour.

Prof. Hort sits on the editorial board of Food Quality and Preference and Scientific Committees for the International Pangborn and Eurosense Symposia. She is a Fellow of the UK Institute of Food Science and Technology and a founder member and past Chair of the European Sensory Science Society and the Institute of Food Science & Technology’s Sensory Science Group.
A problem with many alternative foods developed to replace meat is that they can taste fishy, musty, beany or bitter and have unappealing textures (Tso et al., 2021), and even when technologies improve that sensory appeal, the products still often come second to the products consumers currently eat in market testing. Side-by-side testing of product concepts is a necessary stage of product development to be sure that the products will win out and enable a dietary shift in the right direction.

Convenience is also a key factor for many of today’s consumers (Köster, 2009), hence the emergence of convenient ready-to-cook products on the market, but it is factors such as health and nutrition, environmental impact, and animal welfare that are promoted as the reasons consumers are demanding different food products (Slade, 2018), whilst paradoxically, per capita, meat consumption still appears to be increasing. Meat consumption patterns, however, do vary, even within comparably wealthy countries (Henchion et al., 2014; Tso et al., 2021), highlighting the differences between consumer segments. In many studies, animal welfare ranks lower than other value-driven factors, but often above protein content where alternative proteins are under investigation (Bryant, 2019). This is where the value–action gap can be explained. Cost and sensory experience are generally more important than the values people hold. Of course, this is not true for all consumers, and different segments will have different drivers, but experience tells us that cost and sensory experience are up there for most consumers, even if they do not admit it in a survey. Many consumers may actually believe that some of these values come first for them, until they make the purchase decision, while others may be virtue signaling (Levy et al., 2020), that is, saying what they think they should be saying or makes them look good. The result is the same – behaviours not matching claimed beliefs.

Understanding the relative impact of these different drivers for food choice decision making is a key element to solving the sustainable nutrition question, as global and local strategies that fit with real consumer wants and behaviours need to be developed. The cost and sensory experience of sustainably nutritious alternatives need to be what the consumer will accept.

Another key concept for careful consideration is understanding the different drivers behind willingness to purchase, that is, getting the consumer to buy for the first time, and acceptance, that is, willingness to adopt such foods habitually in their diet. For example, research by Kerry last year identified the drivers for purchase of different plant-based products, as being health (plant-based cheese & ice cream), nutrition (yogurt) and try something new (plant-based meat) (Kerry, 2019). However, when asked which attributes were most important in the purchased product, these were taste, use of acceptable ingredients, and cost. Food can be as healthy as it likes, but if it does not taste good, and is not affordable, consumers will not engage. Bad experiences with one product can then lead to delays in adoption of similar products.

**Consumer perception v. reality**

Understanding consumer drivers is particularly difficult in the future foods space as perception is often not the reality. Taking health and nutrition as an example, media, marketing, and some industries lead the consumer to believe that alternative products are healthier, and indeed sometimes they are. However, to date there is little evidence that replacing meat with alternative products leads to a healthier diet long term (Tso et al., 2021).

Wholefood alternatives may be healthier, but is the consumer really aware that, once cooked, many of the current alternative proteins are higher in salt than the meat version? Cricket flour is higher in fat than wheat flour, for example, and a black bean burger is higher in fat, salt, and sugar than black beans on their own (Tso et al., 2021). Actions industry takes to improve the functionality, processing, or palatability of the products often impact the nutritional value detrimentally. Even when consumer awareness to eat healthier is there, practical barriers such as availability, willpower, and biased brain processing can still push the consumer to the more familiar or social norms (Kahneman et al, 1991).

Environmental impact is also a factor receiving more attention. The general perception is that alternative foods may offer less environmental impact, but the reality can often be the opposite, with processing of some products requiring large amounts of energy or water (Tso et al., 2021). The environmental credentials of future foods will be further scrutinised by the consumer and will increasingly impact developments in the food system. Nevertheless, research shows that where sustainability is concerned, consumers will still prioritise themselves over the planet with cost, convenience and enjoyment – the sensory experience – being important (Blake, 1999). Consumers often motivate themselves to a desired rather than a logical conclusion based on their conscious values (Khan & Dhar, 2006). Of course, some consumers will act on their values, but that segment may not be very large.

There is a role here for the consumer needing to be better educated concerning health, nutrition, animal welfare, environmental credentials, and so on to make better choices, and, if all stakeholders take a role in that, the consumer will be better informed. However, awareness is only a small part of the answer and should not be seen as the only, or key strategy to ensure the consumer makes the better decisions (Bianchi et al., 2018). In fact, understanding consumer behaviour and working with that will be a much more successful strategy.

The psychology of consumer personalities is an aspect that needs consideration for food system change. Some consumers may engage because of having particular personality traits, for example wanting to keep up with the latest fashion (Petrescu & Petrescu-Mag, 2015), others may be novelty seekers interested in the new sensory experiences offered by new foods (Hirschman, 1984). A key question is whether this will lead to a dietary shift long term or just be a fad. Food neophobia, and food disgust traits also have a role to play where many individuals will avoid new foods for some time – if not for ever in the case of food disgust – as these are all traits that consumers and producers may not be aware of but need careful consideration in the sustainable nutrition space (Siegrist & Hartmann, 2020). Different segments will have different drivers: for example, although those interested in organic and functional foods may both be driven by health, they are often different types of consumers, the former being more active and the latter more passive in their food habits (Goetzke & Spiller, 2014).

**Consumer decision making processes**

As previously mentioned, it is wanting that drives consumer behaviours, and much of that decision making process is not driven by rational thinking, but is subconscious (Kahneman, 2011). Tapping into the subconscious elements of consumer behaviours is more likely to better enable a dietary shift. This
means making foods appealing, effortless and the norm (Vermeulen et al., 2020).

By appealing, it means that the sensory experience must be equivalent to or better than what they currently enjoy and be at an acceptable price. It needs to be easily available and easy to use. Finally, such foods need to become the norm. It will no doubt take time for new farm and food processing practices, as well as foods, to become the norm, but if stakeholders and advocates understand this, then the normalisation process can be quicker. Food choices are often an act of self-expression which forms part of a person’s identity. Being labelled as niche because of a food choice behaviour can be segregating – for example, some people may not feel comfortable with food labelled as Vegan (some will) (Greenebaum, 2012) or food that is in a section in the supermarket or café for ‘people with different diets (Schlee, 2017), as cited in Vermeulen et al. (2020). Already strategies adopted by retailers and marketers that help position foods as mainstream, tap into the consumers’ subconscious need to do the familiar and what is the norm and hence increase uptake. In fact, some research has already shown an increased uptake in alternative products when integrated into supermarkets (Holzer et al., 2014).}

**Conclusion**

Considering and working with consumers’ conscious and subconscious wants, needs, and behaviours cannot be ignored when developing new foods systems focused on providing sustainable nutritious diets.

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Feed Our Future: Audience discussion and dialogue*

Discussion Session 4 – Changing the food system?

The audience enjoyed what they described as pragmatic and sensible presentations in this session. Professor Wood’s talk on alternative protein sources of the future was particularly enjoyed for the step-by-step cost calculation for lab-grown meat that was presented as an example. Often costings are presented just as a final value now and in the future, so seeing the breakdown was instructive.

There was disagreement in the room around many aspects of this costing. Several challenged whether pharmaceutical grade fermentation would be necessary, or whether food grade would be sufficient. Other aspects of the costs were hotly debated, emphasising how new and emerging this technology is. Many in the audience expressed the view that Professor Wood’s calculations presented the understanding we have today, but this would change as the food system changed, investment increased, technology developed, and demand for these products increased. It is important to examine where New Zealand might fit in a different food system of the future if new technologies come to the fore.

The question was asked: what else would we have to believe, to believe that lab grown meat could be cheaper than conventional meat? Would the price of energy need to drop a certain amount? And how does the cost comparison change when the environmental impacts of both conventional and lab-grown meat are included in a full cost analysis? It was acknowledged that this calculation would be highly dependent on whether renewable energy was available to produce the lab-grown meat.

Some in the audience were concerned about the food safety of lab-grown meat, as a novel food item. One audience member described it as the ultimate ultra-processed food, and wondered what public perception on lab-grown meat might be, as a food that straddles the alternative protein–processed food axis. Another added that the high number of inputs necessary for lab-grown meat increases supply chain risk, and noted that we do not often consider the requirements to produce the sugar and protein necessary to feed fermenters, along with their footprints and costs. Another consideration is the waste material from fermentation, and how this might be used or disposed of.

Delegates also mentioned that the high number of inputs for lab-grown meat may raise allergenicity risk, without necessarily resulting in a healthier product. One audience member suggested the possibility of genetically modified organisms producing proteins specifically designed for high production in fermenters, rather than trying to replicate existing proteins. Another delegate suggested the integration of fermentation into existing production systems, where synergies between the two could be found.

Outside of the actual growing process, the point was made that the production of lab-grown meat by large corporations would further centralise wealth and control in the food system, with knock-on impacts for society. Furthermore, relying on future technologies to fulfil their promise is a risky strategy.

Professor Hort’s presentation met with almost universal agreement: the consumer does indeed come first, and needs to be at the heart of any change to the food system. Biology, physiological need, appearance, taste, affordability, and nutrition will often trump conscious values when it comes to food-purchasing decisions. Many asked what the priority ordering of these factors will be in consumer choice, and wondered how variable this might be between individual consumers.

There was great interest in how we might influence consumer habits, as well as in the physiology of sensory science. There was discussion of product labelling to ensure consumer understanding, as well as how different consumers can be: early adopters versus risk-averse neophobes. How might the New Zealand consumer change in the future with an aging and more diverse New Zealand population?

Much of the audience discussion demonstrated the overlap between novel or alternative foods and the consumer. For example, how happy will the consumer be about eating insects? Will the current consumer interest in synthetic animal products outlast the desire for natural foods? Both of these are very ‘in’ at the moment, but how long until each is ‘out’?

Delegates also discussed whether alternative proteins should be marketed as such, or whether they should avoid this to become their own novel categories. Furthermore, reducing meat is often a choice people make for health reasons, thus they won’t want a processed lab-grown meat substitute. Similarly, lab-grown meat will not be targeted at vegan consumers, but more likely at meat reducers. How large is this market? Is there more opportunity in selling synthetic proteins as ingredients rather than going to the extra effort of formulating them into foods? Is there an opportunity with allergy sufferers and other niche markets?

The audience agreed that alternative products have to work in the kitchen: consumers will not simply substitute the products they are used to if the substitute is costly or doesn’t taste the same. Repeat purchasing is key for new products. Instead of being a substitute or an alternative, delegates discussed how novel foods could complement existing ones in combined dishes. This could be a way to address nutrient deficiencies.

As an example of changing consumer behaviour, sushi was mentioned. Sushi has risen in popularity in New Zealand, a population that formerly ate more cooked fish. By having a novel format, consumers were convinced to eat raw fish – perhaps anything can be adopted in the right format.

The link was also made between Professor Wood’s point regarding insects as a low-tech solution for both food and feed, and Professor Van Zanten’s talk on circular agriculture and Professor Martindale’s talk on food waste. The audience requested hearing more on the possibilities of aquaculture as an emerging and more sustainable food source than wild-caught fish.

*Discussion summaries were collated by Dr Nick Smith, based on written notes collected from the tables in the room and video recordings of the facilitated discussion sessions on the day.
Verbally and in the written notes, the question of whether New Zealand food production should feed the New Zealand population first and foremost, came up repeatedly. This is a subject receiving much attention at present, and one on which the Riddet Institute and the Sustainable Nutrition Initiative™ are undertaking research. There are many factors at play in this debate, all of which must be weighed to achieve a sustainable New Zealand food system.

Delegates raised the point that the speakers and their topics presented the views of developed, Western world perspectives on food systems. The views of the developing world, the less wealthy, and more diverse cultures was missing in the day, despite being essential perspectives to consider.

The need for full costing of food production and products was also emphasised by many: accounting for environmental and social costs, not just economic costs or ‘prices’ should be a priority.

Discussion of the consumer featured throughout the day, not just following Professor Hort’s talk. Changing consumer behaviour and understanding of nutrition and food was a constant suggestion, but usually without a clear route to achieving this goal. The topic of food labelling, and how this could be made more relevant and informative for consumers was also a recurring feature of the discussions in the room.

Some members of the audience felt that New Zealand has work to do in integrating the strategies of our separate Ministries and Government organisations connected to food. How can the knowledge that exists in New Zealand be better shared, result in behavioural change and identify areas in need of additional research? Do we need a Ministry of Food? Or a National Food Strategy?

Finally, it was often stated that New Zealand is very good at producing animal protein. However, many thought that there is the opportunity to leverage this into non-animal protein systems and lift the total value of New Zealand produce. It was proposed that this could be achieved without compromising our animal production.

*Discussion summaries were collated by Dr Nick Smith, based on written notes collected from the tables in the room and video recordings of the facilitated discussion sessions on the day.
After an excellent day of talks and discussion among the attendees at Feed Our Future, there were many important themes and messages that must be captured. I admit that it is both an honour and a challenge to try to summarise the day’s proceedings.

I joined the Ministry for Primary Industries (MPI) in 2018, and I find myself very privileged to belong to that particular agency considering the conversation that took place at Feed Our Future. Over the course of a few hours, there was excellent discussion about what we at MPI are responsible for in New Zealand: the production and harvesting of food and ensuring its safety for consumers. I have learned much over the last 18 months in this new COVID-19 world about the fragility and the interconnectedness of the food supply chain. It was astounding at times how close we as a country came to shortages in food. This has led to much reflection: even in a country producing food for 50 million people, food security was not assured.

During the COVID-19 lockdown in New Zealand, it became clear that overseas students and tourism were unlikely to be large contributors to gross domestic product for an indefinite period of time. Thus, the main contributor to export earnings would be the primary sector. We were therefore faced, as a Ministry, with the question of how our sector was going to maintain the New Zealand economy.

The government has spent a large amount of money keeping the pandemic out of the country. This has enabled New Zealanders to keep the lifestyle that we have had for the last year. Many people tend to forget this privilege until they see the news from overseas.

Almost a year ago, the Prime Minister launched our economic recovery strategy: ‘Fit for a better world.’ The strategy has three pillars, the first of which is productivity. The aim is to increase the revenue from the primary sector to New Zealand over the next decade by $44 billion, and then gradually increasing thereon by adding value and building off the strong position of our core sectors.

The second pillar is sustainability. As was highlighted in the Feed Our Future discussion, we as a country do not wish to engage in a ‘race to the bottom’: attempting simply to be the lowest footprint producers of food. Instead, we must meet our national climate change targets and the aspirations of our communities and our farmers and growers for freshwater.

The third pillar, also well discussed at the event, was inclusiveness. This reflects the fact that, in a country that produces food for approximately 50 million people, there are those in New Zealand who go home, to school, or to bed hungry. There are also those that eat plenty of food, but not enough of the right foods.

A fantastic piece of nutrition advice that is widely repeated is to walk around the outer aisle of the supermarket when shopping, avoiding the inner aisles. New Zealand produces the foods on the outer aisle of the supermarket. As someone said in the event discussion, we could in the future be the artisan food producers of the world – the country producing those niche products that everybody wants.

Following Professor Wood’s talk on the future of alternative proteins, there was good discussion of whether looking at these

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technologies through the lens of today's technology is appropriate, or if we need to adopt a future lens. I agree completely that we do often examine technologies of the future through the lens of the present. An interesting question arises: can biological technologies, such as fermentation-produced proteins, follow Moore's law: will the exponential increase in technological innovation be matched by an exponentially decreasing price of the technology? Or are there stricter limits to what is possible from biological systems?

The challenge that the world faces is the need to produce almost as much protein in the next 30 years to satisfy global demand as we did in the last 2000 years. As a result, I do not see cell-based meat or plant-based proteins replacing conventional sources: the world will need all of these sources. Some may be higher value and higher cost, and therefore feed the richer of the world, but there must be enough balanced nutrition to meet the needs of the global population. This will come from many and diverse sources.

Professor Singh began the Feed Our Future event with an excellent list of challenges that face the food production sector, from environmental to economic to consumer. There are opportunities in all of these challenges. New Zealand is very focussed on its current large export categories, so perhaps there is opportunity to diversify. Plant-based foods, diets, and alternative proteins are all receiving much attention at present, and perhaps there are opportunities here for New Zealand. It is true that research and development spending outside of the government sector is relatively low in this country, which is its own challenge. The Riddet Institute's vision: future foods in harmony with nature, is exactly in keeping with where I believe New Zealand research must look.

Professor Burlingame then began with a history of the discussion of sustainable food systems, which goes back more than 150 years. However, the discussion really gained momentum in the 1960s. All of you will have heard of the Irish potato famine of the 1800s. But my father, as a farmer there, will tell you that he saw a famine in every decade of his life until 1970. At that point, chemical fertilisers, fungicides, herbicides, and superior breeding stabilised food production – a great win for humanity.

But, as humans are prone to do when something is successful, we used ever more of these technologies. I believe we need to consider that we might have increased the use of some technologies beyond a sustainable use level, as Professor Burlingame suggested, and it is important to reflect on this as we look to the future.

The next speakers covered one of my favourite mantras: nutrition comes first. The discussion after these talks raised the question of why we talk about individual food ingredients or nutrients, when in reality we mix foods together in our diets and obtain more than the sum of the parts. This is an excellent point, and led me to wonder why we break those ingredients down into yet smaller parts. Take saturated fats as an example. We often speak negatively of saturated fats, and yet most foods that contain saturated fats tend also to carry many essential nutrients in high density. A more holistic view on the value of a food or diet is required.

The talks and discussions continued to the topic of affordability and availability of food. A common rhetoric was that talking about these concepts in a global context or even a New Zealand context does not capture the problem entirely. Lockdown restrictions in this country demonstrated that many individuals do not live near a supermarket and rely on fishing or hunting for a major part of their diet. When these people are locked into their house, they are also locked out of their food supply. As we discuss the accessibility of food, it is essential to consider those that are less fortunate.

I always enjoy the passion of Professor Leroy's talks. He takes a line of argument that most people will never have applied to the food system debate: a human psychology perspective. Much of the discussion after his talk centred on the question of why we talk about plants or animals, rather than plants and animals. There is a pressing need for us all to develop our communication awareness: our understanding of how we communicate and how we perceive the communications of others, including the media. The responsibility for this is on each of us as individuals.

Moving to Professor Van Zanten's talk, the circular economy is a concept that the Dutch have been leading the narrative on for some time. As a small country with a large population and a huge amount of food being imported and exported, circular thinking is very valid for them. Rightly, the question was asked at Feed Our Future about what circularity would mean for New Zealand. When we think about the way we produce meat and milk, in many ways it is circular. What is not circular is sending the product overseas, incurring an environmental footprint to us as the producer, rather than to the consumer, as Dr Ledgard pointed out. It is interesting to consider the same situation for fossil fuels: assigning a footprint to the producer rather than the consumer would simply not work, and yet we take this approach for food.

Professor Martindale gave a highly optimistic and informative presentation on food waste. New to me was the approach of using big data and blockchain technologies, giving us the ability to trace food and thus food waste around the world. We now have a huge opportunity to identify where there are greater risks of food waste and put in place mitigation strategies in those markets. This may lead to redistribution or rethinking our supply chains to ensure that there is time to adjust.

It is worth noting that Dr Ledgard and I have known each other for the better part of 30 years. When we first met, he was the foremost Southern Hemisphere expert on nitrogen fertiliser, and today he holds a similar position for life cycle assessment – an amazing achievement. Dr Ledgard demonstrated how good we are in New Zealand at producing food with a low footprint, showing that we can drop a leg of lamb on a supermarket shelf in the United Kingdom at a lower environmental footprint than the average local farmer could. While this is an extraordinary achievement and worthy of celebration, it was rightly pointed out in the discussion that we should not be the 'best of the worst'. Our production systems need to be, and are, working towards being benign in their interaction with nature.
Professor Wood asked and attempted to answer many big questions about alternative food production systems of the future. I am often guilty of looking at these new technologies through a lens of today. However, the figures cited by Professor Wood for the reductions necessary in the price of lab-grown meat before it becomes competitive with conventional production were astounding. We should definitely be asking whether it will be possible to develop these technologies at the rate and price that we have developed non-biological technologies, such as computer chips, or whether there are stricter limits to biology.

The final speaker, Professor Hort, spoke on one of my favourite topics: trying to understand people. As she emphasised, 95% of our decisions are based on fast-thinking intuition, while only 5% are rational. The consumer is king, and it is an incredibly important message to take away from this event that, although we have spoken much about the biophysics, biochemistry and the nutritional aspects of the food system, it is all redundant if a consumer is not going to buy it. We need to understand what motivates their decisions.

Returning to my work at MPI, I have recently been assigned another polarising topic: regenerative agriculture. This is a concept largely of African and North American origin that has recently been talked about in Australia regarding degraded soil systems. An upswell in interest in New Zealand has resulted in the need for the Ministry to investigate the role of regenerative agriculture in sustainable food production systems. Regenerative practices, in our definition, are those that in isolation or collectively can achieve improved outcomes for our productive landscapes, rivers, coastal and marine environments; biodiversity; natural ecosystems and animal welfare; promote health and wellbeing for humans; and ensure we can grow and consume more food and fibre products sustainably. This definition largely encompasses all that we discussed at Feed Our Future.

One attendee said at the event that, while New Zealand cannot feed the world, we can help the world learn to feed themselves. This echoes the words of the Minister for Primary Industries, the Hon Damien O’Connor, who says that New Zealand farmers should be the best farmers for the world, rather than the best farmers in the world. The complexity of the global food system is enormous, yet the narrative is incredibly simple. We cannot ‘greenwash’ our production systems; we cannot be the best of a bad bunch. One of the major points raised at Feed Our Future was that we need to get better at communicating the facts. If the facts and the narrative are lost on the average consumer, then we need to understand better how to communicate with the consumer.

Much food for thought.

\[Ministry for Primary Industries, webpage: https://www.mpi.govt.nz/funding-rural-support/sustainable-food-fibre-futures/regenerative-farming-practices-project/\]
Congratulations

The primary objective of *New Zealand Science Review* is to inform and stimulate. This thematic issue, which contains the papers presented at the conference on Sustainable Production of Foods and the resulting discussions, amply meets this objective. The New Zealand Association of Scientists congratulates the Sustainable Nutrition Initiative™ research programme at the Riddet Institute and the many authors involved. We also wish to particularly acknowledge our Guest Editor, Dr Nick Smith, for his role in coordinating the presentations and recording the discussion sessions.

Why now and why this topic? As pointed out by Distinguished Professor Harjinder Singh, Director of the Riddet Institute, in welcoming participants to the conference, feeding the still-expanding world population in a sustainable manner is one of the great challenges of our time. Current methods cannot meet the rising demand for food protein and are not sustainable. New Zealand, with its experience in producing high-quality premium foods and innovative approaches, is well placed to make a significant contribution.

Each session of this conference raised a series of fundamental questions and produced a lively debate. Nutrition or nutrients? Animals or plants? Useful or waste outputs? Change the system? This is the essence of science. Hopefully, valuable insights will come and lead to technologies that are both productive and benign. There was a strong emphasis on providing validated information to enable consumers to make wise choices that benefit their health and that of the environment.

New Zealand Association of Scientists is pleased to be able to offer a medium for presenting this exchange of ideas to the wider scientific community and the public at large. Readers may note that video recordings of all talks from the event are available at:


Allen Petrey
for NZAS Council
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The Riddet Institute is a New Zealand Centre of Research Excellence, with a world-leading reputation for fundamental and strategic scientific research in nutrition, food science and technology.

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The Association membership includes physical, natural, mathematical and social scientists and welcomes members with an interest in science education, policy, communication and the social impact of science and technology.

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