Bioavailability and micronutrient suitability of protein sources

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Executive Summary

Consumers are becoming more aware of the impacts of their food choices on their health and on the environment. Many people believe that animal source foods are detrimental to both of these factors, whilst consuming only plant source foods will alleviate these problems. In the age of technology, misinformation and disinformation are easy to access and the health and nutrition sectors are not immune from this problem. However, the notion that global health and environmental problems will be fixed by simply eliminating a particular food group is an overly simplistic view of a complex and dynamic situation. Dispelling misinformation and disinformation is imperative to making informed dietary choices, both on an individual basis but also from a policy making point of view.

The objectives of this report were to investigate the bioavailability of protein and micronutrients from different protein sources, and to evaluate the suitability of plants source foods to provide adequate levels of protein and micronutrients to support optimal human health. A review of literature was conducted in conjunction with an interview of a leading scientist in human protein nutrition to analyse the role of protein in dietary choices. This allowed me to draw key themes, apply critical thinking to research and themes, and identify areas of crucial importance.

The gastrointestinal tract and physiology of the human body differs from herbivorous mammals; humans are not able to synthesise the entire range of amino acids and micronutrients endogenously. These amino acids and micronutrients must then be sourced from the diet to ensure optimal health.

Protein quality is characterised by the amino acid profile of the protein, and the ability for this amino acid to satisfy the amino acid requirement of the person consuming the protein. Protein quantity in a diet is irrelevant if the protein in the diet is deficient in essential amino acids; amino acid deficiencies can still occur in someone consuming more protein than required if the protein being consumed doesn't contain sufficient quantities of the most limiting amino acid in the diet.

The ability for nutritional and medical researchers to study human nutrition has limitations due to the constraints involved with this nature of research. Large scale research relies on evidence supplied by individuals which can be subjective. Small scale, more detailed research is extremely variable as each person will respond to the same treatment in a different manner, and this is influenced by many physiological factors. Furthermore, the research is highly invasive, and endogenous biological processes mean that it is often not 100% accurate. Nutritional research using animals also has limitations due to interspecies physiological differences. As a result of these factors, there is strong discord amongst nutritional researchers as to dietary recommendations.

The bioavailability of proteins is defined by the digestibility of the protein, the chemical integrity of the protein and the interference in the metabolism of the protein from other compounds in the food matrix. Research has found animal source proteins to have higher bioavailability than plant source proteins. Furthermore, animal source proteins are also rich sources of micronutrients, which also have high bioavailability for humans. In plant source foods, whilst they may contain micronutrients important for human health, these micronutrients may not be in a form which can be absorbed and utilised by humans, rendering the micronutrient no use.

Micronutrient deficiencies and amino acid deficiencies are widespread in populations who rely on staple based diets. These diets are confined to a small range of nutrients due to geographical and

financial constraints. The incorporation of animal source proteins in these diets would aid in alleviating malnutrition amongst these populations by providing both high quality proteins and a wide range of bioavailable micronutrients.

Recommendations:

- Advocate for scientific verification when policy is created with respect to restrictions on food groups
- Invest into food security and agricultural sustainability in third world countries to allow them to be self-sufficient and free from malnutrition
- Understand the research accurately to ensure confounding factors don't influence interpretation of nutritional research
- Reduce restrictions on productivity to ensure malnourishment and food scarcity doesn't worsen in vulnerable populations due to policy decisions in wealthy countries
- Identify limitations in a diet where food groups are eliminated
- Advocate for accuracy on food labelling to inform consumers of true nutritional value of foods
- Take ownership of the promotion the wholesome benefits of our products
- Ensure perceived environmental benefits of dietary choices are accurate

1. Introduction

Historically, our evolutionary progress has been associated with the ability to use technology to increase our nutrient intake; millions of years ago this was linked with an increase in hunting abilities and subsequently, the domestication of both animal and plant food sources also helped to accelerated our cognitive abilities (Pereira & Vicente, 2013). Currently, the global population consumes a diet which is approximately 85% derived from plant source foods, and 15% derived from animal source foods (Fletcher, Finer, & Smith, 2020; McNabb, 2020). Both food sources are essential for the optimal functioning of our digestive system, and our overall health. However, this pattern of food consumption is not consistent across the global population; some regional populations consume substantially higher than 15% of their diet as animal source foods, whereas, some populations consume almost 100% plant source foods.

In 1995, the Food and Agricultural Organisation (FAO) for the United Nations reported that over 4 billion people relied on rice, wheat and maize based staple diets, whilst more than 1 billion people relied on root and tuber based staple diets. However, these staple foods do not provide adequate nutrients, and a variety of foods are required to meet nutritional demands (FAO, 1995). Fast forward 25 years to 2020, Adesogan, Havelaar, McKune, Eilittä, and Dahl (2020) reported that over 2 billion people remain subjected to micronutrient deficiencies globally. Furthermore, over 150 million children under 5 years of age have their growth stunted and millions of other children have impaired cognitive function, all resulting from malnutrition. This malnutrition is most prolific in poor populations and especially in populations which rely on staple based diets.

Over recent years, within wealthy populations, there is increasing belief that animal source foods are detrimental to human health, are damaging to the environment, and are dispensable in our diet. A recent report published by the EAT-Lancet Commission testified against the use of animal source foods (Commission, 2019). Of 1324 g recommended food intake per day, the Commission recommended only 84g was obtained from animal source food, although this was 'optional', and not necessary in a 'healthy diet'. Yet the Commission then contradicts its recommendation and states that gaining adequate quantities of micronutrients from plant foods alone can be difficult. The report labels red meat as 'less healthy' which is what it also labels sugar.

The EAT-Lancet report has garnered a lot of criticism by nutritional experts (Adesogan et al., 2020). Whether or not animal source foods are dispensable in the human diet is a fervently debated topic; Muehlhoff, Bennett, and McMahon (2013) argued that increasing consumption of dairy products and meat is providing important nutritional benefits to a large number of people in developing countries. However, there are still millions of people suffering from malnutrition due to their inability to afford animal source foods. Massey University Professor Paul Moughan supported this theory, reporting that there is a changing perception amongst nutritional researchers about the importance of animal based proteins in a well-balanced diet (Newman, 2020). In 2011, the FAO appointed Professor Moughan as the Chairman of an expert panel commissioned with reviewing dietary protein quality in human nutrition. Moughan reported that the view that the global environmental and health concerns would be alleviated by increasing crop production at the expense of animal production was an 'overly-simplified and wrong conclusion based on very simplistic analyses, undertaken by people who don't understand the role of proteins in nutrition and health'.

The objectives of this report are to investigate the bioavailability of protein and micronutrients from different protein sources, and to evaluate the suitability of plants source foods to provide adequate levels of protein and micronutrients to support optimal human health.

2. Methodology

This research used a literature review and an interview with a leading scientist in the New Zealand food protein science industry. This has allowed me to draw key themes, apply critical thinking to research and identify areas of key importance.

The literature review was used to understand what scientific resources are available for the general population as well as policy makers and global food industry influencers in making dietary recommendations, or personal dietary choices.

The interview with the leading scientist in the New Zealand food protein science industry was a semi structured interview with the aim of discussing the role of protein within the global food system and the link between proteins and micronutrients, as well as discussing the role of protein and the general micronutrient status in individuals from a dietary choice perspective.

3. Discussion

3.1 Structure of Gastrointestinal Tract

The gastrointestinal tract (GIT) in humans exhibits features from both herbivores and carnivores (Pereira & Vicente, 2013). A key component of the GIT of herbivores is the ability to digest fibrous plant materials. Herbivores such as ruminants contain large quantities of microbes at the beginning of their digestive tract. These microbes ferment plant fibre and have the ability to synthesise protein – more importantly essential amino acids – from the simple nitrogenous compounds of urea and ammonia. The host animal would not be able to synthesise these essential amino acids without this symbiotic relationship with microbes. Fatty acids are produced as a by-product of this fermentation, which are then absorbed by the host animal and utilised as an energy source. In this fermentation process, the microbes have not only released nutrients from plant material which would have otherwise been unavailable to the host animal, but they have also improved the quality of protein supplied to the host animal by synthesising essential amino acids from simple nitrogen sources or low quality protein that doesn't contain essential amino acids. These essential amino acids are then absorbed from the small intestine and provide the majority of the protein supply to the host animal.

The human GIT comprises of a simple acid stomach and a well-developed small intestine which has the ability to digest a varied diet (Pereira & Vicente, 2013). A key difference from the digestive tract of ruminants is the lack of an active microbial population at the beginning of the digestive tract, only in the latter part in humans. Therefore, while the microbes in the large intestine will produce essential amino acids, these cannot be absorbed from the large intestine, and will be excreted in faeces (McNabb, 2020). However, the fatty acids produced in this fermentation, as well as urea, ammonia and a number of essential vitamins can be absorbed from the large intestine, hence this process is still beneficial (Brittanica).

In essence, humans are unable to synthesise all amino acids, hence it is critically important that we consume adequate quantities of essential amino acids in our diet. Whereas, the microbiota present in herbivores produce an amino acid profile which supports growth and production in the host animal. Figure 1 shows the complex passage of proteins through the digestive tract of humans, and into tissue for utilisation, with no ability to synthesise essential amino acids.

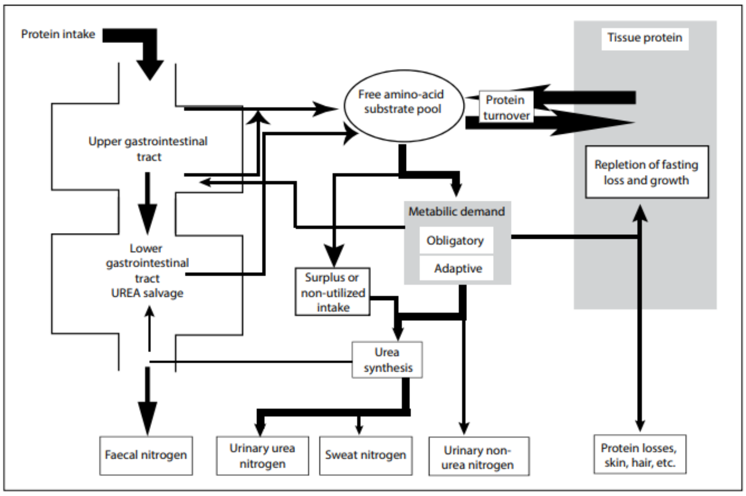

Figure 1. Protein metabolism in humans. Sourced from WHO, FAO, and UNU (2007)

3.2 Protein Quality vs. Protein Quantity

Proteins are made up of individual amino acids which are bound together to form peptide chains. These peptide chains then bind in certain patterns to form their own structures, depending on their amino acid composition, and this determines the form and function of the protein (Food and Nutrition Board, 2005; Ramírez-Sánchez, Pérez-Rodríguez, Delaye, & Tiessen, 2016). When we think of protein, we often think of proteins which perform structural and mobility related functions such as muscular proteins, however, all animals and plants contain an extremely vast array of proteins, in varying forms, not only for structure, but to facilitate and regulate all biological processes and virtually all biochemical reactions which allow for the multitude of life forms on Earth (Education, 2014). Appropriately, to match the extremely vast difference in function of proteins, their form can be equally as diverse. It is therefore logical that proteins of differing function have differing amino acid compositions, and furthermore, different sources of protein (animal vs. plant, muscle vs. enzyme) provide a different composition of amino acids.

In terms of human nutrition, protein is one of the three macronutrients (protein, fat and carbohydrate) required to sustain life. Provided that there is a sufficient supply of macro and micronutrients in the diet, proteins can be synthesised endogenously.

Historically, protein consumption and recommended daily protein intakes were focused on protein quantity, which was analysed using nitrogen balance studies in human adults. This involves measuring the nitrogen intake of the adult, and the nitrogen excreted through urine and faeces (FAO, 2011). The level of protein which was deemed to be sufficient was the level which balances these daily losses of nitrogen, without altering the protein mass in the body of a healthy adult, and must take into account the protein required for maintenance, growth, physical activity, gestation and lactation where applicable. However, a limitation to this system is that this does not identify the optimal level of daily protein intake for optimal health, which is a more multifaceted matter than the simple approach of a nitrogen balance for determining minimum protein requirements.

In recent years, protein consumption and daily protein intake recommendations have evolved to recognise the importance of the quality of the protein consumed, rather than simply the quantity. The quality of a protein is related to the individual amino acid composition of the protein, the digestibility of the amino acids supplied and the ability for that amino acid profile to satisfy the metabolic needs of the human at a particular age and stage of development (Food and Nutrition Board, 2005; Schaafsma, 2000). It has been recognised, that there are vastly different metabolic effects resulting from the digestion of different amino acids (FAO, 2011; Food and Nutrition Board, 2005). Furthermore, amino acid intake will generally be disproportionate to the amino acid requirement of the individual.

Free amino acids cannot be stored in the human body, and must be partitioned between incorporation into protein synthesis or oxidation (FAO, 2011). Furthermore, there are nine amino acids which humans and animals are not able to synthesise endogenously, and therefore, must obtain from their diet (Table 1). These amino acids are called essential / indispensable amino acids, whereas, amino acids which humans can synthesise endogenously are called non-essential / dispensable amino acids, as it is not essential for us to obtain these amino acids from our diet (Food and Nutrition Board, 2005). If there is an individual essential amino acid deficiency in the human, protein synthesis will be limited to the exhaustion of that amino acid. The amino acids which are not deficient will become surplus and will be oxidised. Thus, the nutritional benefit of a protein, for the efficiency of amino acid utilisation will be limited to the quantity of the most limiting amino acid in that protein; referred to as the limiting amino acid theory (Food and Nutrition Board, 2005; Harper, Benevenga, & Wohlhueter, 1970). Hence, the quality of a protein is related to the ability of the protein to satisfy the amino acid requirement of the human consuming the protein, which is more important than consuming a large quantity of amino acids surplus to the requirement for protein synthesis.

Table 1. The essential and non-essential amino acids. Adapted from WHO et al. (2007)

Essential Amino Acids	Non-essential amino acids
Lysine	Alanine
Isoleucine	Aspartic acid
Leucine	Asparginine
Methionine	Glutamic acid
Valine	Serine
Phenylalanine	Arginine
Threonine	Cysteine
Tryptophan	Glutamine
(Histidine)	Glycine
	Proline
	Tyrosine

Note: Histidine is considered an indispensable amino acid due to the detrimental effects of health and function to individuals when the diet provides insufficient histidine.

For these reasons, there has been a new system of protein quality assessment developed to evaluate a protein in terms of the supply of limiting amino acids to humans. This takes into consideration individual amino acid composition of a protein, and the value of this protein in terms of meeting the amino acid requirement for humans at varying stages of maturity. This system is called the Digestible Indispensable Amino Acid Score (DIAAS) system (FAO, 2011).

In addition, the true value of a protein source is also influenced by the availability of those amino acids for digestion and absorption. Therefore, corrections for this may be required as the digestibility of different amino acids is not equal. The previous protein evaluation systems used by the FAO did not account for differing digestibility of individual amino acids; rather, it used a standard protein digestibility score for all amino acids. The DIAAS aims to take into account the differing digestibility of these amino acids, and therefore should be more accurate in defining the supply of amino acids from a food protein (FAO, 2011).

In human cells, proteins are continually being synthesised and degraded. Amino acids synthesised in human cells are non-essential amino acids, while both essential and non-essential amino acids are degraded in the cells (Food and Nutrition Board, 2005). This means that if dietary supply of essential amino acids is insufficient, there will be a net loss of essential amino acids, and if not replenished, this will cause a loss of protein. These lost proteins may then provide an endogenous source of these limiting amino acids, however, the amino acids may not be reutilised in the same tissue they were catabolised from, and further, the efficiency of their use is not 100%, and there will still be a net loss of essential amino acids (Food and Nutrition Board, 2005).

3.3 Limitations to Protein Evaluation Methods

Protein metabolism is an extremely dynamic process involving multiple factors which influence utilisation of protein, including the physiological state of the person consuming protein as well as the quality of the protein itself.

For these reasons, evaluation of the suitability of a protein source to satisfy the requirements of the person, or to compose nutritional guidelines is a complex process. Numerous animal and human methods are available for estimating protein metabolism in human nutrition, but all of these methods have limitations.

One important method used to analyse amino acid digestibility is the method of ileal amino acid digestibility. This is where the known amino acid content of the ingested food is compared with the amino acid content of the digesta in the ileum (WHO et al., 2007). However, a major limitation to this method of amino acid digestibility is that endogenous proteins and nitrogen containing compounds are secreted into the small intestine to aid in the digestive processes. Therefore, not all amino acids in the ileum are of dietary origin, and this method can only be used as a crude estimation of protein metabolism (WHO et al., 2007).

Furthermore, this is a very invasive method of protein evaluation as it requires a nasal tube to be inserted from the mouth all the way to the ileum through the gastrointestinal tract (FAO, 2011). However, this is considered to be a more accurate measurement of amino acid digestibility than that of measuring faecal amino acid output. Microbes resident in the large intestine will utilise non-protein nitrogen sources and undigested protein sources from the ileal effluent to synthesise their own protein, therefore the amino acid profile of these microbes will distort the faecal amino acid profile (FAO, 2011). This means that using ingested food and excreted faecal material in a simple subtraction model cannot be used for determining amino acid digestibility.

Animal models have been identified to be indicative of human protein metabolism, however, these are also not perfect (FAO, 2011). Pigs and rodents have been identified as the closest and most practical animals to use for these models. Using animal models allow for researchers to utilise more invasive techniques of research such as using cannula into the digestive tract or slaughtering the animal to take measurements of digestion and metabolism. However, each species have differing characteristics of digestion and metabolism, and therefore, these animal models cannot be used to directly predict what will happen during digestion in humans and must be used as indicators of protein metabolism instead (FAO, 2011).

While the model for using ileal amino acid digestibility as a predictor for protein quality in human nutrition has limitations, especially with regard to the invasive nature of the method, it is currently thought to be the most accurate predictor of protein quality (FAO, 2011). It is considered that the ileum is the best place in the small intestine for this measurement to occur as by this stage, the largest majority of the endogenous amino acids have been reabsorbed, and this is prior to the amino acid distortion of the large intestine (WHO et al., 2007).

3.4 Human Protein Requirements

Daily dietary protein requirements are influenced by the metabolic demand of a person for protein, and the efficiency with which protein is utilised in the body (WHO et al., 2007). The metabolic demand of a person is influenced by the basal protein requirements to maintain protein stasis, and the special requirements for circumstances such as growth, physical activity, pregnancy and lactation. It is believed that the amino acid profile required for 'special demands' for protein such as growth, pregnancy and lactation differs from the amino acid profile required for basal protein requirements, presumably due to the specific requirements of these physiological states (WHO et al., 2007).

The efficiency with which protein is utilised in the body is determined by factors associated with the protein such as amino acid profile, and digestibility of the protein, and external factors such as the physiological state of the person consuming the protein. For example, if a person is in negative energy balance, amino acids may be deaminated and used as an energy source, rather than being absorbed for utilisation in protein synthesis (WHO et al., 2007). Furthermore, micronutrient requirements must also be sufficient for optimal protein metabolism.

It is important to note that at a zero protein intake, there will be a net loss of protein in the body, excreted in the form of nitrogen. During catabolism of protein, some limiting essential amino acids may be recycled and utilised for protein synthesis; however, some limiting essential amino acids may be used for the production of metabolites essential for systemic functioning, which are then degraded to nitrogenous compounds (WHO et al., 2007). This reduces the quantity of the particular essential amino acid in the body, and contributes to the net loss of protein /amino acids. Further losses occur in the form of sloughed intestinal proteins, hair, skin cells and other secretions, and these losses vary between individuals and within an individual at differing stages of diurnal cycles and the life cycle, as well as different physiological states. Figure 2 displays how amino acids can enter the available amino acid pool from endogenous origins or from dietary origin.

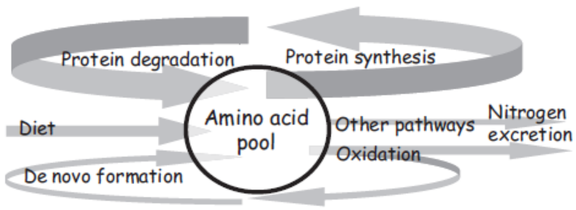

Figure 2. Amino acid transfer into and out of the amino acid pool. Sourced from (WHO et al., 2007)

The body is largely unable to store free amino acids for future use. The demand for individual amino acids is met by the free amino acid pool (displayed in Figure 2), which is very tightly regulated. The source of amino acids in the free amino acid pool is from digested and absorbed amino acids from dietary origin, amino acids from proteolysis, and amino acids resulting from de novo synthesis of amino acids (WHO et al., 2007). Once an amino acid enters the amino acid pool, there is no bias for endogenous or dietary amino acids in protein synthesis or amino acid utilisation within cells.

Individual amino acid requirements vary depending on the factors discussed above, but a deficiency in one particular amino acid will impact many systemic functions as overall protein synthesis will be limited to the quantity of that first limiting amino acid. The amino acid which is commonly the most limiting amino acid in diets, especially diets high in cereals, is lysine (WHO et al., 2007). The World Health Organisation recommends an intake of 30 mg /kg body weight per day. While the total daily indispensable amino acid requirement is 184 mg /kg, a diet will not be sufficient to meet the protein requirements of the individual unless all amino acids are present in sufficient quantities to meet the daily requirement for the respective amino acid. This is due to the fact that amino acids cannot be stored and will therefore need to be either utilised as a functional amino acid, or deaminated to be used as energy. Once the requirement is met for the limiting amino acid, surplus amino acid consumption will result in the deamination of all further amino acids.

3.5 Implications of Protein Deficiency

An average 70 kg male has about 11 kg of protein in his body – approximately 43% of this protein is in the form of skeletal muscle, while another 30% is made up of a combination of blood and skin protein (Food and Nutrition Board, 2005). Organs such as the liver and kidneys make up a combined 10% of body protein, and the remaining organs contribute to most of the remaining protein in the body.

As a human grows from neonate towards adulthood, both the overall body protein percentage and the composition of protein in the body change. Neonates have lower skeletal muscle proportions and higher brain and visceral protein than adults (Food and Nutrition Board, 2005).

Protein is required for a wide array of functions including the growth and maintenance of body tissue – tissue growth, functional (organs, gastrointestinal and systems such as lymphatic), biochemical functions such as enzyme production, host defence systems such as the immune system, hormonal control and tissue repair (FAO, 2011).

Dietary protein deficiencies or conditions where protein metabolism is compromised can have severe or even fatal implications for a person. In the short term, protein deficiency will impact growth and tissue repair, immune function, mental capacity including mood and sleep patterns, muscle mass and detoxification of chemical agents and the anti-oxidant system. In the longer term, this suboptimal functioning of these processes are likely to impact life course events and increase the rate of aging, increase the rate of age related functional losses and increase the chances of disease through impaired host defence systems (FAO, 2011).

Interestingly, despite the very large diversity of proteins and enzymes in the body, approximately half of the protein in the body of an average, healthy person is made up of only four proteins – myosin, actin, collagen and haemoglobin (Food and Nutrition Board, 2005). Collagen alone may comprise 25% of the body's protein mass in a healthy, average person, and it is selectively retained if a person is protein deficient and catabolism of other protein occurs.

If a person is malnourished, or has a protein deficiency, their body will start to use up what's called the 'labile protein reserve'. This labile protein reserve is thought to mainly be derived from the liver and visceral tissues, as animal studies have shown the protein portion of these tissues to be depleted by up to 40% during a period of malnutrition or protein depletion while skeletal muscle depletion occurs more slowly (Food and Nutrition Board, 2005). This protein catabolism contributes to daily essential amino acid requirements for essential bodily functioning. It is important to note that the body does not store protein for use in times of need in the same manner as it stores fat and glycogen to use when energy is deficient. The protein used as labile protein reserve is functional protein, which quickly puts the body into a situation of suboptimal systemic functioning.

Protein deficiency has adverse impacts on all organs in the body and it is thought that damage to brain function from protein deficiency in babies and young children may persist in the long term (Food and Nutrition Board, 2005). Protein deficiency also has negative effects on the immune system, weakening the body's ability to fight infections. Furthermore, if nutritional deficiencies occur during the pubescent stage of development, if not remedied, this may permanently stunt their development (McNabb, 2020).

3.6 Bioavailability of Proteins and Individual Amino Acids

The bioavailability of an amino acid refers to the proportion of the amino acid present in a food matrix which can be absorbed and utilised for metabolism by the human (FAO, 2011; WHO et al., 2007). The bioavailability of individual amino acids is influenced by the following three factors:

1. Digestibility
2. Chemical Integrity
3. Interference from other compounds in the food matrix

Digestibility describes the true absorption of the amino acids from the gastrointestinal tract and is considered to be the most influential factor in the bioavailability of amino acids. However, it is pertinent to note that amino acid digestibility in humans can be very difficult to accurately measure, and is not fully understood (FAO, 2011). It is known that digestibility of amino acids do vary from person to person and in differing dietary scenarios and metabolic states.

Amino acids occur in food matrices in the form of either free amino acids, or amino acids as the building blocks for peptide chains and proteins as a whole (FAO, 2011). The catabolism of proteins in the process of digestion is separated into two categories; the release of peptide chains from a food matrix (free amino acids exempt) and the hydrolysis of peptides bonds, releasing individual amino acids. The hydrolysis of these peptide bonds is not standard across a peptide chain, and different enzymes will be required for the hydrolysis of peptide chains from different sources of protein. This contributes to the difference in digestibility of particular protein sources.

In terms of nutrition, the most important factor in protein is the amino acid composition. However, other factors such as the structure of a protein will affect its' digestibility. If all proteins were equally digestible, our bodies would be continuously catabolising their own tissue, therefore, some proteins have protective structures to inhibit their catabolism. Proteins situated in the gastrointestinal tract which act as intestinal mucins are highly glycosylated, while keratins are insoluble in water - both factors rendering these proteins indigestible (Food and Nutrition Board, 2005).

The chemical integrity of an amino acid refers to the proportion of the absorbed amino acid which is in a form metabolisable by the human digestive system (FAO, 2011; WHO et al., 2007). Low utilisation can result from processes such as heat-treatment of foods or chemical processing of foods. Some proteins are unable to be broken down by proteolytic digestive enzymes due to their physical characteristics or chemical composition (Food and Nutrition Board, 2005). During heat treatment and chemical processing, some amino acids can become unavailable due to denaturing of the protein. Denaturing of a protein is an irreversible change in the three dimensional structure of the protein which causes a loss of its function and biological activity (BiologyOnline, 2021). Some amino acids are more prone to increased loss of bioavailability than other amino acids from processing. Therefore, it is important that in these situations, the truly utilisable proportion of amino acids are reported, not just the total quantity of the amino acid.

Another factor impacting the bioavailability of an amino acid is the presence of other compounds in the food matrix that may inhibit the absorption of the amino acid (FAO, 2011). These compounds are called bioactive substances, and they may be in the form of other proteins, or non-proteins. They may interfere with the digestibility of the amino acid, or they may interfere with the post-absorptive utilisation of an amino acid. These antinutritional factors can be naturally occurring, formed during processing, or the result of genetic modification - tannins, phytates and lectins to name a few (FAO, 2011; WHO et al., 2007).

It is important to note that bioavailability of protein is not synonymous with the utilisation of protein in the process of protein turnover. The bioavailability of protein is outlined above. However, protein can be utilised for different metabolic purposes depending on the physiological state of the human and the nutritional makeup of the diet (FAO, 2011). As discussed previously, if protein is consumed in excess or if dietary energy content is insufficient, the protein may be deaminated, and the carbon skeleton will be used for ATP production. In this case, the protein has been utilised, but not for body protein synthesis or an alternative anabolic pathway. This factor complicates the ability to predict protein metabolism; the ileal digestibility method of protein utilisation is simply a mathematical equation, which has no ability to account for the difference between protein being absorbed for protein metabolism, or being utilised for ATP production.

FAO (2011) reported that with respect to novel protein sources, it is important to be mindful of the potential for antinutritional factors and chemical integrity of proteins to reduce the bioavailability of amino acids within a food matrix.

In practical terms, differing bioavailability can result in large differences in the amount of protein available from a food. Table 2 shows the differences in the protein content of different food sources. Also shown are the corresponding digestibility and bioavailability values of each food group. It is valuable to have a resource which quantifies the protein availability of these food groups, in terms of claims made surrounding 'high protein'. Foods such as legumes which are claimed to be a 'high protein' food source are compared with animal source proteins. On average, animal based foods provide 18.1 g of bioavailable protein per 100 g of food, whereas, plant based foods provide an average of 4.9 g of bioavailable protein per 100 g of food. Furthermore, unprocessed meats alone provide an average of 23.5 g of bioavailable protein per 100 g of food. Interestingly, the average protein content for legumes and pulses, which are often claimed to be high in protein, provide an average of 5.3 g of bioavailable protein per 100 g food, which is less than 1/4 of the protein provided by the same quantity of unprocessed meats and 1/3 of the protein provided by the same quantity of the average of all of the animal proteins. This may be due to the large variation in protein content of legumes and pulses. Table 2 highlights the necessity for food to be carefully selected in situations where dietary protein content is low. Nuts and seeds are the outlier in the plant based foods, providing more than double the protein of most other plant based food sources. However, they still provide almost half the amount of digestible protein as unprocessed meats.

Table 2. Protein content, digestibility and bioavailability of differing protein sources. Adapted from Golding (2008)

Food Group	Protein Content (g / 100 g food)	Protein Digestibility (%)	Bioavailable protein on average (g / 100 g food)
Cow's milk	3.8	90	3.4
Dairy products	13	92	12
Eggs	12.3	86	10.6
Chicken (cooked)	25.9	88	22.9
Beef (cooked)	27.2	95	25.9
Pork (cooked)	27.5	88	24.3
Lamb (cooked)	25.5	88	22.5
Venison (cooked)	30.1	88	26.6
Cold cuts and cured meats	20.3	93	18.7
Sausages	15.1	91	13.7
Fish and shellfish	21.6	89	19.2
Legumes / Pulses	6.9	77	5.3
Nuts and Seeds	15	82	12.3
Breakfast cereals	7.3	75	5.5
Yeast breads	10.6	93	9.8
Tortillas	7.6	90	6.9
Rice	2.4	79	1.9
Pasta	5.4	83	4.5
Noodles	4.2	83	3.5
Other grains	3.4	80	2.7
Vegetables	2.1	65	1.3
Fruits	0.8	65	0.5

It is also interesting to note the pattern of digestibility and the difference between plant based and animal based protein sources. The animal foods have an average protein digestibility of 89.8%, compared with 79.2% for the plant foods. In my opinion, this is a reflection of the similarities between the animal products that humans consume and the metabolic processes and functions for those animals, and our own tissue and metabolic functions and processes. We have evolved very differently to plants, and this is reflected in the differences in our tissue compounds and metabolic functions and processes; hence, our simple digestive tract is able to more easily extract nutrients from animal products than plant products. In comparison, ruminants have evolved the ability to form a symbiotic relationship with prokaryotic organisms in their digestive tract, which allows them to extract nutrients from a solely plant based diet. As discussed previously, plants tissue may even appear to have similar compounds, but these may be isotopes of the same compounds which may render them ineffective for human metabolism.

3.7 Micronutrients

Micronutrient deficiencies are exceptionally common in poorer nations, where diets are dominated by cheap or easy to grow food sources (FAO & WHO, 2001; Pee & Bloem, 2007). Typically, these diets will be heavily plant based, as animal products tend to be more expensive, and are considered luxury products.

While micronutrients are abundant in both plant and animal source foods, their bioavailablitiy and bioactivity must be taken into consideration. Some plants may appear to contain adequate quantities of specific micronutrients, but if these are not available for either absorption from the GIT or use by human tissue, a deficiency of this microonutrient may occur if not supplemented with appropriate forms of the micronutrient. This can occur due to ‘pseudo-vitamins’, which are very similar to the form of the vitamin, but they have no known therapeutic effect in humans. One example is psuedo-vitamin B12 found in some algal species which is unavailable for absorption by humans, but other examples include vitamins which may have therapeutic effects for other mammalian species, but have no know therapeutic effects for humans.

Animal products are often a dense source of largely bioavailable and bioactive forms of micronutrients, whilst having a low caloric density. Interestingly, concentrations of water-soluble vitamins in human milk is dependent on the maternal dietary concentration of water-soluble vitamins, whereas cows have the ability to synthesise these water-soluble vitamins *in vivo*, which means that they don’t need to consume these vitamins in their diet (Wijesinha-Bettoni & Burlingame, 2013).

While this report does not have the scope to evaluate the bioavailability of all micronutrients, some important factors are highlighted with regards to major micronutrient problems within the global food system.

It has been reported that several billion adults and children are impacted by a form of micronutrient deficiency (Muehlhoff et al., 2013). There have been many development programmes aimed at eliminating iron, iodine and Vitamin A deficiencies, but despite these efforts to eliminate micronutrient deficiencies, a vast number of people still do not consume enough dietary zinc, folate and vitamin B12. It is postulated that access to higher quality and more diversified diets are crucial to combatting this form of malnutrition (Muehlhoff et al., 2013).

3.7.1 Vitamin B12

Vitamin B12 is an essential vitamin which is only synthesised by certain bacteria – humans do not possess these bacteria and vitamin B12 therefore needs to be derived from the diet. Vitamin B12 is found in animal products such as meat, milk, eggs, fish and shellfish, but it can also be derived from some plants and algae (Watanabe, 2007). However, the bioavailability of vitamin B12 differs with differing dietary sources, and is also influenced by the dose of vitamin B12 in a meal; the GIT reaches saturation and there is a maximum of vitamin B12 that can be absorbed at a time. Bioavailability ranges from approximately 56-89% from sheep meat, approximately 61-66% for chicken meat, 42% for fish meat and is very poorly absorbed from eggs with a bioavailability of approximately 9% (Watanabe, 2007). Some plants contain vitamin B12, however, not all plant derived B12 are bioavailable to humans, and some plant sources contain pseudo-vitamin B12 which is inactive in mammals. It is reported that only two species of edible algae contain bioavailable vitamin B12, while vitamin B12 in other edible algae species is unavailable for human absorption and will not aid in vitamin B12 supplementation. Spirulina has also been perceived a source of vitamin B12 for vegetarians and vegans, however, the very high concentration of vitamin B12 present is not only unavailable to humans but can block the absorption of bioavailable vitamin B12 (Watanabe, 2007). Methods of detecting and measuring vitamin B12 in foods have led to the inaccurate assumption that some foods will be good sources of vitamin B12 for people who cannot attain their vitamin B12 from animal products. However, this method has been insensitive to pseudo-vitamin B12 which has led to incorrect conclusions.

3.7.2 Vitamin A

Globally, there are approximately 100-140 million children who suffer from a vitamin A deficiency (Pee & Bloem, 2007). Staple diets can be very deficient in vitamin A, however, FAO and WHO (2001) reported that plant foods rich in carotenoids could significantly improve the vitamin A status of populations at risk. Contrastingly, Pee and Bloem (2007) reported that while forms of vitamin A such as pro-vitamin A are present in plant foods, the mechanisms in the human digestive tract for converting these forms of vitamin A to forms available for absorption are highly inefficient. The authors reported that estimates for the efficiency ranged from 6:1 to 26:1 for micro g beta carotene: retinol activity equivalent. It was recommended that to reduce the prevalence of vitamin A deficiency worldwide, animal foods rich in vitamin A (liver or dairy products) be incorporated into the diet of populations at risk of deficiency. FAO and WHO (2001) also supported the notion of including animal foods in the diet to satisfy the vitamin A requirement due to the superior bioavailability of vitamin A from animal foods.

3.7.3 Iron and Zinc

FAO and WHO (2001) reported that cereal and tuber-based diets can often yield deficiencies in iron and zinc. Whilst legumes can be utilised to increase the iron content of the diet, this is not a perfect strategy. Animal foods contain iron in the form of heme and non-heme iron, whereas plant foods solely contain iron in the form of non-heme iron (Sharp, 2010). Heme iron is absorbed intact and is much easier for the body to utilise than non-heme iron. Furthermore, absorption of non-heme iron is subject to significant interference from other compounds in the diet. FAO and WHO (2001) reported that it is not possible to meet the recommended levels of iron and zinc in staple based diets, and that animal products must be incorporated into these diets to ensure iron and zinc deficiencies do not occur. For both iron and zinc, a 50 g portion of meat, poultry or fish per day will supply adequate levels of each of the bioavailable nutrients.

3.7.4 Omega-3 fatty acids

Whilst α-linolenic acid (ALA) intake is similar between vegetarians and non-vegetarians, there is virtually no eicosapentaenoic acid (EPA) and docosahexanoic acid (DHA) in a vegetarian diet. ALA can be endogenously converted to EPA and DHA, however this process is inefficient and time consuming, and vegetarians have been found to have lower plasma, blood and tissue levels of EPA and DHA (Saunders, Davis, & Garg, 2013). Furthermore, interactions with other polyunsaturated fatty acids may inhibit the conversion of ALA to DHA (Gibson, Neumann, Lien, Boyd, & Tu, 2013). EPA and DHA have both been reported to be strong factors supporting human health (Lane, Derbyshire, Li, & Brennan, 2014), therefore it is highly important for humans to optimise EPA and DHA levels. These authors reported that there was strong evidence that nut and seed oils did not provide any conversion of ALA into DHA, however, algal oils did appear to provide ALA which was able to be converted to DHA. This highlights the importance for the bioavailability of nutrients to be considered when formulating diets which exclude major food groups. Currently, the best source of omega-3 fatty acids is considered to be fish oils, however vegetarian sources include flaxseed, echium, walnut and algal oils (Lane et al., 2014).

3.7.5 Conjugated Linoleic Acid (CLA)

CLA is a naturally occurring fatty acid which is in abundance in pasture fed ruminant products – milk or meat (Anonymous, 2021; Wijesinha-Bettoni & Burlingame, 2013). Many micronutrients such as CLA, vitamin B12 and vitamin K2 are very highly abundant in pasture fed animals due to the ability of the animal to harvest the nutrient from pasture, and by utilising their extensive gut flora, they are able to convert it to a bioavailable form which is absorbed in their small intestine (Wijesinha-Bettoni & Burlingame, 2013). These micronutrients can be incorporated into their tissue or milk and will then be in a form which is also bioavailable for humans. If the ruminant is not fed pasture, the micronutrient will not be available for them to consume. This illustrates why pasture fed meat or dairy has vast health benefits compared with grain fed ruminants.

3.8 Dietary Implications of Protein Source

Plant proteins are consumed in a food matrix, rather than in isolation, and this can have both positive and negative impacts (Richter, Skulas-Ray, Champagne, & Kris-Etherton, 2015). On the positive side, whilst consuming plant proteins, other beneficial macro and micronutrients /bioactive compounds such as fibre and antioxidants may be consumed. However, on the negative side, in order to achieve an ideal amino acid intake on a solely plant based diet, the diet has the potential to become more calorie dense than the equivalent amino acid intake from a combination of animal and plant sources (McNabb, 2020).

Similarly, whilst the consumption of animal based proteins can provide a more ideal concentration of highly bioavailable amino acids and micronutrients, these foods can come with a higher intake of saturated fats. In this case, high fat protein sources are not recommended, and lean protein sources are recommended.

An interesting developing area of science is investigating the impacts of specific amino acid and protein levels which promote optimal functioning of organs and positive health outcomes for people of different ages and health conditions (FAO, 2011). This may again change perception of different sources of proteins.

Whilst both animal source foods and plant source foods are rich in a wide variety of nutrients, both the bioavailability of the nutrients, and the practicality of consuming sufficient levels of nutrients must be considered. FAO and WHO (2001) express the importance of maintaining a diverse diet in order to ensure adequate intakes of all micronutrients. Therefore, inclusion of all food groups is important. The most beneficial method of acquiring micronutrients is through the diet – supplementation of micronutrients is not a sound method for inclusion of micronutrients due to issues with bioavailability (McNabb, 2020).

Meat is rich in protein, zinc, B-vitamins, A-vitamins and iron (Rohrmann et al., 2013). Whilst grains and leafy green vegetables provide sources of iron and folate, the bioavailability of iron and folate from meat is much higher than it is from the vegetable counterparts (Rohrmann et al., 2013). Therefore, to consume the daily requirement of iron and folate solely from vegetables, intake must be very high. It is also logical to ensure that the calorie dense foods in a diet also be nutritionally rich foods. Hence, the rich micronutrient composition of animal source foods make them a sensible component of a diet.

Williams (2007) analysed the nutrient composition of beef, veal, lamb and mutton and compared the composition of 100g of each meat, with the Australian recommended daily intake (RDI) for each macro and micronutrient. Protein content ranged from 21.5 – 24.8 g/100 g raw lean meat, and fat content was between 1.5 and 4.7 g /100 g raw lean meat. The protein content per 100 g increases when the meat is cooked, due to the decrease in water content. Mutton was considered to be the most micronutrient dense meat of the sampled meats.

While protein content in lean meat is relatively consistent between cuts of meat, the fat content can vary largely (1-37%) depending on the cut of meat (Williams, 2007). There has been a trend over recent decades to decrease the fat content in meat, achieved through targeted breeding, feeding and butchering preferences. Fillet steak has gone from approximately 10% fat content in the 1980's to 6.6% in 2002. An advantage to New Zealand production systems in terms of fat content in red meat is the fact that the vast majority of animals are pasture fed, as opposed to being grain fed (Williams, 2007).

Milk also contains highly bioavailable forms of micronutrients such as calcium, magnesium, selenium, riboflavin, vitamin B12 and vitamin B5 (Muehlhoff et al., 2013). These nutrients, along with a lot of the micronutrients contained in meats are often difficult to obtain in a staple based diet such as tuber- or cereal based diets. Therefore, even small inclusions of these animal source foods in the diet for populations consuming staple based diets can make substantial improvements to the micronutrient status of the population. Furthermore, the high lactose content in milk aids the intestinal absorption of nutrients such as calcium, magnesium and phosphorus, and also aids the utilisation of vitamin D (Wijesinha-Bettoni & Burlingame, 2013).

Cow's milk is one of the most universally available protein sources for human consumption, more than 80% of global milk production in 2010 was cows milk (Wijesinha-Bettoni & Burlingame, 2013). Interestingly, there is a higher protein and mineral concentration in cows milk than there is in human milk, due to higher requirements for these nutrients by calves, due to their rapid growth rate (Wijesinha-Bettoni & Burlingame, 2013). Furthermore, the cows milk protein is of high quality in terms of human dietary requirements due to its balanced range of essential amino acids, including lysine. Whilst many staple based diets are deficient in one or more amino acids, the overall quality of these diets can be improved by including milk and milk products. Wheat and maize based diets generally contain only 57% of the lysine requirement, whilst cassava based diets contain only approximately 79% of the required levels of leucine, isoleucine and valine (WHO et al., 2007). Wijesinha-Bettoni and Burlingame (2013) reported that over 600 million people in regions such as Asia, Latin America and Africa were reliant on cassava based diets, and the addition of milk products into their diet would be vastly beneficial to their overall health.

3.9 Labelling of Protein sources

It is staggering that protein can be simply labelled as a quantity on food labels, considering the complexity of protein composition and value in terms of satisfying the daily requirement for amino acids. Consumers make dietary choices based on these labels, yet the protein quantity in a food may be completely irrelevant if the protein quality is inadequate for meeting the consumers' daily dietary amino acid requirements. It seems like an arbitrary label for a protein to be labelled as 'high protein', if it is unable to be metabolically beneficial as a protein. Due to this shortfall in labelling of proteins, consumers could eat three times their daily protein recommendation but still be deficient in particular amino acids.

The FAO propose an international system which would provide consistency in protein claims. This would ensure that false claims cannot be made where a product is called 'high protein' when it will be insufficient to meet amino acid requirements. Table 3 illustrates the need for protein quality to be labelled on foods rather than simply protein quantity. FAO (2011) have developed a standardised system for protein evaluation, which assesses the protein quality with regard to the ability of the protein to meet daily amino acid intake, considering both amino acid balance, and the bioavailability of particular amino acids. This would prevent protein quality from being misconstrued on food labelling. It is clear from Table 3 that while there is 25% less total protein content in peas, whole milk powder provides almost double the bioavailable amino acids required for meeting the daily amino acid requirement. As a result, peas wold be labelled as a 'low protein' source, whilst milk powder would be labelled as a 'high protein' source. It is staggering that within the current food labelling guidelines, wheat, which provides one third of the amount of bioavailable and metabolically useful amino acids as milk powder, can share the claim to being a 'high protein' food source.

Table 3. Currently accepted protein labelling based on quantity compared with proposed new system for labelling protein based on quality and quantity on food labelling. Source FAO (2011)

Food	Amount	Protein content (g/100g)	DIAAS[1]	Judged quality	Eligible for claim based on quantity	Eligible for claim based on quantity and quality
Wheat	100 g	11	40	Low	Yes, high	No, none
Peas	100 g	21	64	Low	Yes, high	No, none
Whole milk powder	100 g	28	122	High	Yes, high	Yes, High

[1] DIAAS calculated using true ileal indispensable amino acid digestibility values and reference amino acid pattern for child (6 months to 3 years).

The digestible indispensable amino acid score (DIAAS) system assesses the protein for its ability to satisfy the daily amino acid requirement of an individual. This system is proposed by FAO (2011) as a method of standardising advertising of protein sources. There would also be agreed thresholds for claims of 'source' or 'high' protein foods. The next phase of true international standardisation is to settle on an internationally agreed method of biological analysis of the amino acid composition and bioavailability of the protein.

3.10 Health Claims

While it is commonly claimed that a vegan or vegetarian diet is healthier than an omnivorous diet, nutritional experts lack a consensus on this theory as research findings do not conclusively support it (Dobersek et al., 2020; Richter et al., 2015; Rohrmann et al., 2013). The problem with such claims and researching such themes, is that the research is very commonly confounded by multiple factors. Differing regions, populations and cultures have different responses to animal and plant based protein intake. For example, as a rash generalisation, an omnivorous diet can be higher in processed foods, and a vegan or vegetarian diet can be higher in whole food consumption. In each case, there are a number of other factors within the diet that affect the health of the individual, independent of their source of protein. Rohrmann et al. (2013) reported that health conscious vegetarians and non-vegetarians had a statistically significantly lower mortality risk than the general British population, and found similar results in a German study. When populations in the same socio-economic bracket were compared for health parameters and mortality, there were no differences between vegetarians and non-vegetarians. It was not the avoidance of meat that was the health promoting factor of the vegetarian population that was impacting their health status and mortality (Dobersek et al., 2020). Furthermore, it has been concluded that the type of animal or plant protein had more of an impact on the risk of disease than the source of the protein (animal or plant) (Richter et al., 2015). This is likely due to other non-protein food components present in the food matrix that the protein is consumed with, as well as other lifestyle factors such as level of physical activity, body mass index (BMI) and smoking, drug and alcohol status (Dobersek et al., 2020). This form of confounding results is something that researchers and health officials need to be wary of, and especially when results of such research is used to influence consumer choice and public health recommendations.

Richter et al. (2015) also report that after numerous meta analyses, there is sufficient evidence that processed red meat contributes to the risk of coronary heart disease, but not unprocessed red meat. While dietary guidelines were to reduce red meat intake to reduce the dietary saturated fat and cholesterol content, red meat was not found to be the highest contributor to saturated fat in the American diet. Richter et al. (2015) go on to explain that processed meat contains approximately 400% more sodium and 50% more nitrates (preservatives) than it's unprocessed counterpart. These confounding factors are likely to be part of the reason for the increased disease risk associated with these foods, as well as other dietary factors, and not the red meat portion of the food matrix.

It becomes increasingly important to distinguish between specific forms of proteins when considering the differences in consumption patterns between different cultures. While American and Japanese populations consume similar total quantities of animal protein, the form of animal protein differs strongly with Japanese populations likely to consume predominantly fish, while American population consume predominantly red meat (Richter et al., 2015).

Furthermore, when considering healthy levels of protein and carbohydrate in a diet or whether or not the source of protein is improving or worsening health outcomes, it is important to consider the source of carbohydrate as well. Richter et al. (2015) reported that health metrics weren't increased in women with a higher protein intake in Sweden, but there was an increase in measured health metrics in women with a higher protein intake (proportional to carbohydrate intake) in women from the US. However, Swedish women consume higher rates of cereals compared to US women. So if the increased protein intake was at the cost of cereals, then this may not impact health metrics. Whereas, in women from the US, it is presumed that the increased protein in the diet replaced refined carbohydrates. Refined carbohydrates are rapidly metabolised and likely to cause a spike in blood glucose and insulin levels, increasing the risk of insulin resistance. Whereas, complex carbohydrates such as whole grains and cereals are metabolised more slowly, and have beneficial nutritional factors such as dietary fibre, magnesium and potassium, which are likely to improve health metrics. Therefore, it isn't necessarily the protein in these diets which most strongly affect the health metrics, and this needs to be taken into consideration with this research. This also highlights the need for critical analysis of such dietary research, as without very strict controlled settings, confounding factors can overpower genuine results.

Whilst some reports claim that red meat is carcinogenic, it is important to distinguish the difference between a food matrix containing carcinogenic compounds, and there being a strong link to increased rates of disease resulting from the consumption of this food. Furthermore, the concept of level of consumption is often the difference between a food being termed as healthy or harmful. Even the most basic and essential aspect of human life illustrates this concept; if a person doesn't have enough water, they will die, but if a person has too much water, they will die. Similarly, the vast majority of the nutrients in animal protein food matrices are essential not only for 'health' but for maintaining life. However, some of these food matrices also contain nutrients which are known carcinogens, and if consumed in high quantities, are likely to cause a person to develop disease. Rohrmann et al. (2013) reported that even a nutrient as essential as iron can have carcinogenic properties if consumed in high quantities. Many people would consider iron as 'natural', along with many other foods in the diet, but even 'natural' foods consumed in excess are likely to have detrimental impacts to one's health.

FAO (2011) reported a scarcity of long term studies giving accurate representations of health outcomes in relation to protein intake. A major limitation of large scale nutritional research is that it is not possible to have strict controls in place, as would occur in small scale research. This type of research relies on people's account of their diet and lifestyle over long periods of time, which can be very subjective. Large scale research is required to analyse such health conditions as cancers, or heart disease, as small scale research would not provide results with high levels of significance. However, the margin for error in large scale trials can be large, due to the subjective nature of requiring individuals to relay a personal account. Hence, there is considerable discord in the literature as to health outcomes with regard to many different dietary recommendations.

In addition to the health claims around a vegetarian /vegan diet compared with an omnivorous diet are claims that animal products are worse for the environment, and that if the entire world's population were to stop eating animal products, we would need less land for agriculture. However, this claim is completely unsubstantiated. The land currently used for agriculture in different parts of the world does not all look the same. Once the lowly productive land, which is uncroppable is taken into account, there is not enough land to grow diverse and highly productive crops to feed the global population (McNabb, 2020). Furthermore, global food production needs to increase by 70% by 2050 to meet the growing global population (Moughan, 2020). WHO data from 2001 stated that at that time, 842 million people were undernourished, and tragically, children were overrepresented in this group. In the face of increasing regulations surrounding global food production, without very careful construction of regulation to protect productivity, it seems that reduced productivity is a very likely outcome. Unfortunately, the first people to be impacted by food shortages will be the people who are already on the margins of food shortages, yet cruelly, these people are generally the people a long way from where the regulations are created.

3.11 EAT-Lancet Report

The EAT-Lancet report released in 2019 was damning for the future of livestock based agriculture. The EAT-Lancet report recommends minimal animal source foods (ASF), of 14g /day of red meat, 29 g /day chicken or poultry, 13 g /day eggs and 28 g /day of fish. Combined, this makes up only 84g, of 1323.8g /day in the recommended diet. The report states that the ASF are 'optional' for a healthy diet, however, it somewhat contradicts itself to state that gaining adequate quantities of micronutrients from plant foods alone can be difficult. In addition, the report labels red meat as 'less healthy' as it does processed sugar (Commission, 2019).

The report is suggestive that animal source foods are the culprit for dietary related deaths, and conveys a message that moving to 'healthy diets' as described above would reduce diet related mortality by 11% per year. However, the report fails to acknowledge the likelihood that the health benefits of this diet would largely stem from a reduction of processed foods in the diet, and rather misleads people to believe that red meat and other animal source foods are the problem in modern diets.

The report states that the adoption of 'healthy diets' would improve the health of billions of people. Together with the grouping of red meat with added sugar in the unhealthy category, this insinuates that the consumption of red meat and ASFs as a whole are bad for human health, and that moving away from ASFs will have a major improvement for health outcomes for billions of people. However, the truth is likely that health outcomes would be improved for billions of people were they to increase the proportion of ASF in their diets, while a large number of people in the developed world would improve their health outcomes by reducing the proportion of processed foods in their diet.

The EAT-Lancet report has been harshly criticised; Adesogan et al. (2020) condemned the authors lack of consideration for marginalised women and children in low- and middle-income countries, whose diets are commonly deficient in adequate levels of macro- and micro-nutrients. Whilst not an academic source, in her blog post, Nina Teicholz quotes a large amount of criticism of the report from various nutritional and medical experts. Among the criticism is the inability of the 'healthy diet' to account for the nutritional needs of pregnant women, children, teenage girls, aged persons and impoverished persons. What's more, people outside of the general population would need to take supplements to compensate for nutrient deficiencies within the 'healthy diet' (Teicholz, 2019).

Teicholz (2019) explains that while it is portrayed that the group of 37 authors are from a wide cross section of experts in nutritional and medical research, 31 of the 37 members had published works in favour of vegan or vegetarian diets, and 7 of the members attended a Stockholm Think Tank aimed at reducing or eliminating animal source foods the benefit the environment. Teicholz (2019) reports that it was not required for the authors to declare conflicts of interest, and that the group gave very little consideration to any science which was antagonistic to their own views or agendas.

Professor Paul Moughan from Massey university stated that the idea that the global food challenges could be solved by increasing crop production at the expense of animal production was an overly simplistic view, held by people who didn't understand the role of proteins in health and nutrition (Newman, 2020). Whilst these comments were not directed at refuting the EAT-Lancet report, it does show that within the scientific community there certainly isn't unanimity in the views held by the authors of the EAT-Lancet report, and in fact there is strong discord in the proposed solutions to the challenges facing global food security. Professor Moughan acknowledged that perceptions are changing amongst the scientific community surrounding the benefits of animal proteins in human nutrition.

The report also delved into the environmental debate surrounding food production. While the EAT-Lancet authors reported that even small increases in the consumption of animal source foods would make environmental goals 'difficult or even impossible to achieve', Adesogan et al. (2020) were scathing on the validity of the report due to the authors inability to accurately estimate the tremendous variability in the environmental impact of livestock production.

The report uses emotional language and confusing statistics to push an agenda. The report warns of 'disastrous consequences' of inaction, and acknowledges that there will be opponents to their views, which can be used as a tactic to reduce peoples willingness to openly oppose their views.

The report is focused on environmental concerns in a one dimensional manner. Food production, environmental concerns and climate change are inexplicably linked by 'experts' and politicians, yet there lacks a singular, overarching model, which takes into account multifaceted outcomes, from improvements in production, technology, environmental outcomes, dietary optimisation, reduced food wastage and other strategies to optimise environmental outcomes. The models used by experts tend to focus on only the impacts of their own 'solutions', rather than taking into account solutions from other models. Therefore, the degree to which change is needed may be significantly less than what is currently perceived, as solutions can begin to have compounding improvements, when combined with other systematic improvements. This is like changing one aspect in an ecosystem and expecting only one implication.

The report had some encouraging strategies about the future of the food production sector, such as improving efficiency of fertiliser and water use, recycling of nutrients, decreasing yield gaps on current cropland and improving biodiversity on farms (Commission, 2019). However, these concepts should be achieved at practical rates without sacrificing the productivity of the food producing sector, and invalidated fear tactics should not be used to change people's food choices –especially when there is significant discord amongst scientists as to the health outcomes of such choices.

3.12 Wider dietary themes

When it comes to dietary guidelines and claims of health benefits, there is a tsunami of information, misinformation and disinformation available to consumers. It has been proven that the Mediterranean diet is the 'healthiest' diet in the world (McNabb, 2020). Researchers have concluded that this is due to the vast variation of foods consumed by this population. To think logically, if a very wide variety of foods are consumed in small quantities, there will be an array of micronutrients and bioactive compounds consumed and the risk of both subclinical nutrient deficiencies and overconsumption of specific food groups is very low. Furthermore, researchers found that people of Mediterranean decent, that resided in different regions, for example Italian people living in Australia, were even healthier than their counterparts who live in their countries of origin. This is due to an even more diverse influence on the food consumption habits, for example, the influence of Asian style food as well.

The geographical location, as well as the affluence of a population will dramatically influence the dietary induced health metrics of a population. This is not only for obvious reasons in regards to affluence, but due to the foods that are available in that region, and the ability of the population to import and transport a wider variety of foods to incorporate into their diets. The smaller the range of foods in a diet, the smaller the range of micronutrients and bioactive compounds there will be. Therefore, in regions where the majority of protein is obtained from plant sources, adding animal proteins into the diet is likely to increase the health metrics of the population, while the reciprocal is true for populations who consume a diet heavily dominant in animal protein (Richter et al., 2015).

It is essential to have a varied diet and to understand that even if a nutrient is present in a food, the nutrient is not automatically in a form available for human utilisation. There is a very complex process of absorption and availability for use of nutrients by human tissue which can cause deficiencies if not well understood.

Whilst there is a social movement away from animal based products in some parts of the world, it is important to consider both our nutrition and the global food system as a whole, ensuring that all of our macro and micronutrient requirements are met, and that our choices don't disadvantage people in third world countries where food scarcities are a very real and life threatening problem.

4. Conclusions

Plant source foods and animal source foods should both be part of a healthy diet. This research indicates that the inclusion of animal source foods in a well-balanced diet allows humans to thrive due to the wide array of nutrients supplied by animal source foods, and the high level of bioavailability of these nutrients. Plants source foods also provide vital nutrients in a human diet, however, some nutrients which are present in both animal source foods and plant source foods may not act similarly during digestion or metabolism in humans. Some nutrients from plant source foods can be inadequate to meet metabolic demands, despite appearing to be present in abundance in the plant source food. In order to optimise health, a well-balanced diet should consist of a majority of unprocessed plant source foods, with the remainder of the diet consisting of unprocessed animal source foods.

Whilst vegan diets are becoming popular due to perceived health and environmental benefits, it may be very difficult on a vegan diet to avoid amino acid or micronutrient deficiency. These may even be subclinical deficiencies, which may have long term implications to the individual.

In staple based diets, animal source foods are often luxury items due to their cost. The inclusion of animal source foods in these diets can substantially improve the health of these populations due to the provision of amino acids and /or micronutrients which are deficient in the diet. Billions of people world-wide are limited to staple based diets due to poverty.

Creating legislation which limits agricultural production will exacerbate these nutritional problems in low socioeconomic countries as animal based proteins will become more expensive.

Consumers and policy makers need to be wary of the limitations of nutritional research. Individual dietary guidelines and the global food system both need to be considered as multifactorial systems whereby altering one factor will have multiple outcomes.

Protein quality is not currently labelled on food labels. Protein quantity does not accurately convey the ability of a protein to meet the biological requirements of the person consuming the protein. This can lead to amino acid deficiencies given that the physiological state of a person, their age and their diet will all influence their requirement for particular amino acids.

Animal source foods are widely promoted by many nutritional scientists, and the accuracy of perceived environmental implications is questioned by some researchers (Adesogan et al., 2020). The World Health Organisation continues to endorse animal source foods as being the best available source of high-quality nutrient-rich foods for children aged 6-23.

Plant source foods have a large place in a balanced human diet, but animal source proteins should not be eliminated.

5. Recommendations

- **Advocate for scientific verification:** Consumers and policy makers should thoroughly research the scientific basis for implementing or recommending dietary changes to exclude certain food groups. Misinformation and disinformation is easy to find regarding dietary choices. Whereas, sound scientific reasoning for the importance of the source and form of our food is less forthcoming. The true bioavailability of proteins and micronutrients need to be taken into account when formulating diets.
- **Invest into food security and agricultural sustainability in third world countries:** Efforts should be made to increase the availability of animal source foods to populations where staple-based diets cause widespread micronutrient deficiencies and malnutrition. This could be through investment into agriculture in the regions where these malnutrition problems are present, in order to increase self-sufficiency of these populations.
- **Understand the research accurately:** When interpreting nutritional research, careful consideration needs to be given to the limitations of the research. Meta-analyses need to be critically evaluated to ensure confounding factors don’t skew results. With smaller scale

research, consideration needs to be given for the margin for error due to the complex nature of the research, especially with respect to protein digestibility's and absorption. It should also be noted that making a single alteration in a diet will likely have multiple implications.

- **Identify dietary limitations:** Individuals who wish to adopt a vegan diet should familiarise themselves with the health risks of subclinical or clinical micronutrient and amino acid deficiencies to ensure they can identify these problems, should they occur. Furthermore, individuals should thoroughly research whether the perceived environmental benefits relate to material environmental benefits.
- **Reduce restrictions on productivity:** Whilst we need to be strongly vigilant to look after the environment, we need to be careful that we only change practices at a speed which doesn't exacerbate food shortages. As food shortages increase the price of food globally, the first people to be impacted by these food shortages are those who are already struggling to afford food and avoid malnourishment.
- **Advocate for accuracy to inform consumers:** The agricultural industry should advocate for accurate labelling on foods to reflect protein quality, not just protein quantity. Protein quality should include an analysis on the ability of the protein to meet amino acid requirements of the consumer. There should also be requirements for what can be labelled as 'high protein', again both as protein quality and protein quantity.
- **Promote the wholesome benefits of our products:** The agricultural industry should take ownership of promoting the health advantages of animal source foods. By conveying with the public the importance of animal source foods for an individual's health as well as within the global food system, public perception of agriculture should improve. Improved public perception of agriculture is vital for maintaining a social license to farm and for ensuring policy makers to aid in optimising agriculture.

6. Future Research

An area for future research is whether or not novel protein sources such as plant based meats and lab grown meats have the ability to meet the requirements for amino acids and micronutrients in the same way that animal source proteins do. It is currently extremely difficult to acquire information on individual products in these categories. However, anecdotal evidence suggests that these protein sources may not be the 'silver bullets' that they have been marketed as. There are likely to be limitations on these products from a nutritional perspective and a practical perspective. Scalability is one challenge for lab grown meats. In addition, these meats are a product of their ingredients. Whilst this sounds logical, it presents a problem; animal meats are rich in bioavailable micronutrients, whereas, if these particular micronutrients are not added to the lab grown meats, these meats will not provide the same array of essential micronutrients as animal proteins. What's more, if these micronutrients are artificially added to these lab grown meats, will they then effectively be a supplement with reduced bioavailability compared with animal based micronutrient sources? Plant based 'meats' will provide an array of nutrients, however, the same concepts surrounding bioavailability apply as described above.

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