Food and health

Sir: why do my parents always tell me I need to eat more fruit and vegetables instead of pasta and pizza?

Photo by Fernanda Lima: https://www.pexels.com/photo/woman-eating-pizza-16014835/

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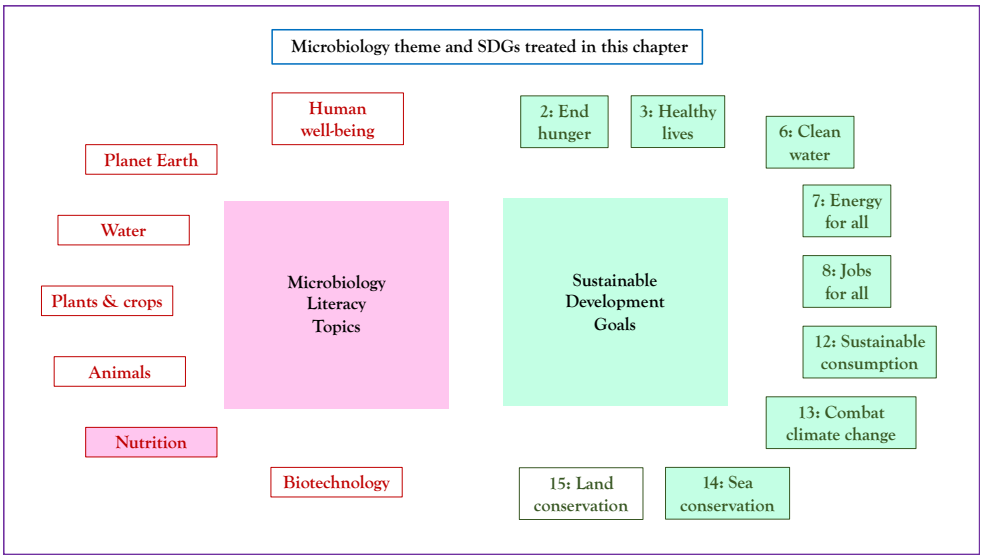
Storyline

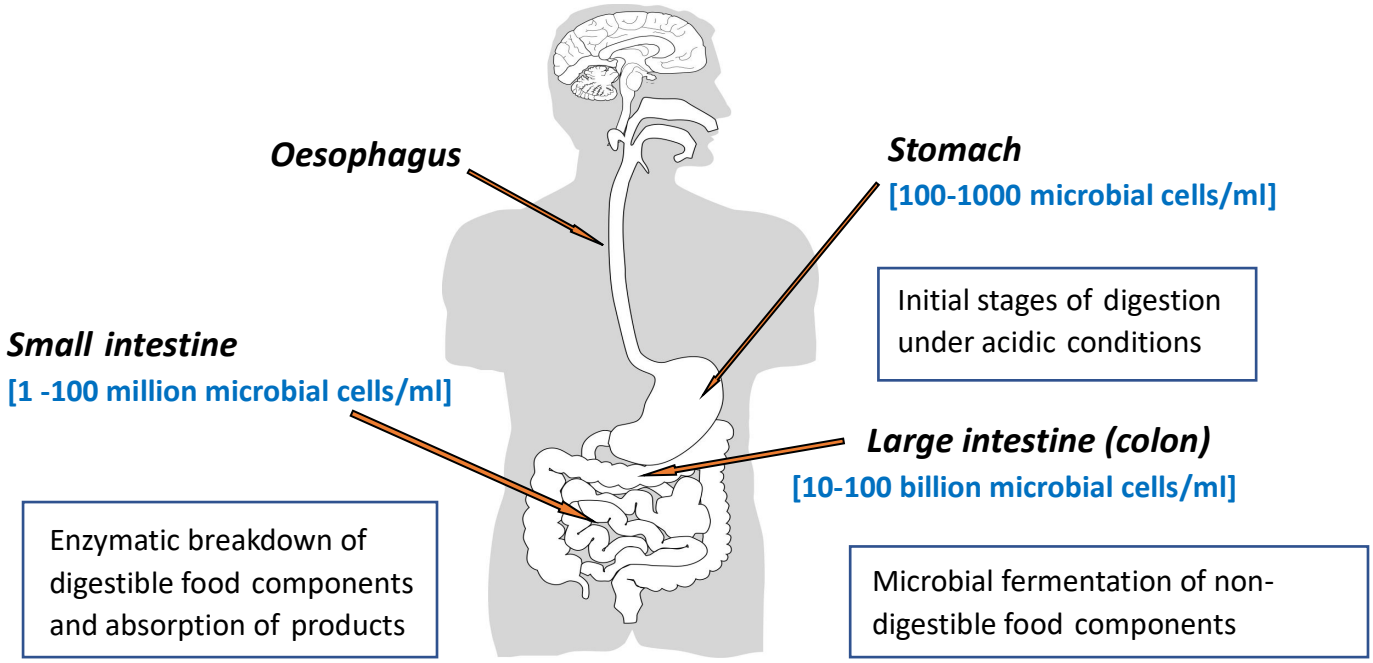
Food supplies the energy and nutrients that we require to live, grow and stay healthy. But it can also be the cause of poor health if we eat too much of the wrong types of food and not enough of the food ingredients that maintain and promote good health. As well as energy, a good balance of vitamins, minerals, essential amino acids (for making proteins) and beneficial fats is important for our health. Before our body can make use of food that we eat, it must be broken down (digested) so that it can be easily absorbed into the blood stream. This all happens in our digestive tract (gut), mainly in the stomach and small intestine. However, not all the food that we eat can get digested in this way. Some of it, which is referred to as plant fibre, remains undigested and is then available as food for the complex community of gut microorganisms (our gut microbiome) that exists in the large intestine. We benefit significantly from this microbial fermentation of fibre, as its releases short chain fatty acids (SCFA) that the body can absorb as additional energy sources. These same microbes also release certain 'phytochemicals' from plant fibre that are beneficial to health. Overall, the microbiome exerts numerous influences on our metabolism and immune function, some of which are beneficial and some damaging to health. Eating the right foods, including, cereals fruit and vegetables that contain fibre (and whose phytochemical content results in a rainbow of colours) can help to encourage a healthy balance of bacterial species and fermentative activity to promote health.

The Microbiology and Societal context

The microbiology: microbial colonisation of the human gut in infants and adults; how this is influenced by dietary intake and individual variation; consequences of microbial colonisation for health; potential for new therapeutic approaches via dietary manipulation of the gut microbiome; food safety. *And peripherally for completeness of the story:* food production; microbial greenhouse gas production from ruminants; plant-based meat substitutes; policy decisions on health and nutrition; regulatory issues related to food and farming *Sustainability issues:* health; food and energy; economy and employment; environmental pollution; global warming



Food and Health: The Microbiology



The human gastro-intestinal tract

1. The micro-organisms in our gut. Our intestines are home to huge numbers of microorganisms, which are at least as numerous as our own human cells that make up the body. The highest concentrations, up to 100 billion microbial cells per millilitre, are present in the large intestine (Figure 1). The overwhelming majority of these microorganisms are bacteria that thrive at low levels of oxygen (known as 'anaerobes'). Gut microorganisms grow by exploiting various energy sources that come from the diet, specifically that part of the diet known as 'fibre' that is resistant to being digested by our own enzymes in the upper gut (stomach and small intestine). Most fibre consists of carbohydrates of plant origin that we are not equipped to degrade by ourselves because we lack the necessary enzymes to break them down. Some additional energy sources used by gut bacteria are derived from the host, for example mucus that is produced by the lining of the gut, and special compounds in breast milk known as human milk oligosaccharides (HMOs). The latter play an important role in shaping the species composition of the human gut microbiota in breast-fed infants. In adults, the fermentation of these various energy sources by gut microorganisms gives rise to short chain fatty acids (SCFA) that play an important role in maintaining the health of the gut lining, as well as systemic health and immune function. Furthermore, gut microorganisms have an important influence on the development of the immune system and of the gut itself in early life. On the other hand, we know only too well that some gut microorganisms are damaging and promote disease. This makes it vitally important to have the right balance of microorganisms in one's intestine and we know that diet has a strong influence in determining this balance.

2. Adequate consumption of plant fibre in our diet is important for human health. Adequate dietary fibre is widely considered to be important for the prevention of several types of cancer and in helping to prevent heart disease and type 2 diabetes. Major sources of fibre, which comes mainly from plant material and consists of material that cannot be digested by our

own enzymes, include cereals, fruit and vegetable (Figure 2). The benefits of fibre intake are supported by evidence from epidemiology which is the branch of science that deals with the spread and control of diseases [1]. These diseases impose a major, and increasing, burden on our national health services. Official guidelines for the level of fibre consumption recommended for health maintenance in adults have been increased in recent years both in the UK (to 30 grams per day) and USA [2].

Sources of dietary fibre

3. Functional foods that target the gut microbiome are important economically. Foods that are intended to beneficially modify our gut microbiome are important economically to the food industry and account for a significant fraction of commercial food sales in many countries. These include 'live' yoghurts that deliver probiotic organisms to the gut that have become popular with consumers both for their taste and for their perceived health benefits. In addition, foods are being introduced to the market that are fortified with 'prebiotics'. Most prebiotics are non-digestible carbohydrates, such as inulin, that escape digestion by host enzymes and are intended to promote the growth of beneficial microorganisms within the gut microbiome.

4. Individuals can differ widely in their response to dietary fibre intake. Different individuals do not always respond in the same way to the food they eat. This can reflect genetic differences between people. For example, many adults worldwide (indeed a majority) are intolerant of milk products in their diets because excessive microbial fermentation of the disaccharide lactose (present in milk) in their large intestine causes them digestive discomfort. This is because they lose the ability that they possessed as infants to digest lactose due to low levels of the enzyme lactase, in the small intestine, when reaching adulthood. On the other hand,

people who retain this ability (this includes many northern Europeans) experience no problems from consuming milk products [3].

5. Some subgroups of individuals may show intolerance of high fibre intake. Some groups of people can show intolerance of high fibre intakes for reasons that are not fully understood. For example, some of those who suffer from Irritable Bowel Syndrome may find their symptoms, such as stomach cramps and bloating, are made worse by consuming amounts of fibre that lead to excessive microbial fermentation in the intestine. Such individuals may be recommended diets that are low in non-digestible, fermentable carbohydrates (known as 'FODMAPS' (Fermentable oligosaccharides, disaccharides, monosaccharides and polyols) diets).

6. It is becoming possible to design diets that control the composition of the gut microbiome. The species composition of the gut microbiome is affected by what we eat. Since different members of the gut microbiome have different health consequences, this creates the potential to modify diets to benefit health. For example, new prebiotic fibres, including oligosaccharides, which are polymers of a small number (typically three to nine) monosaccharide units, might be chosen with the aim of promoting bacteria that suppress inflammation or prevent infection. There is interest in developing certain members of the healthy microbiome as novel therapeutics. Their establishment might also be promoted by supplying a compound in the diet that promotes the growth of a therapeutic microorganism, thus adopting what is referred to as a dual 'synbiotic' approach.

7. Some of the variation between individuals in their gut microbiome composition appears to be discontinuous. In humans the colon is home to trillions of bacterial cells. These bacteria belong predominantly to five different phyla that together include many hundreds of bacterial species that are commonly found in the gut. The species composition of the gut microbiome varies between individuals for a variety of reasons that include differences in dietary intake. For example, human populations can be subdivided into people for whom the main representatives of the phylum Bacteroidetes within their gut microbiome are *Bacteroides* species, and people for whom *Prevotella* species are dominant. There is evidence that this difference, which is not simply due to diet, has consequences for health status and responses to dietary intervention [4].

8. Perturbation of the microbiome by antibiotics can cause health problem in the short and long term. The 'normal' (unperturbed) gut microbiota helps to protect against infectious organisms in a variety of ways. When the gut microbiome is perturbed, for example by administration of an antibiotic that kills or inhibits the growth of many microbes, this protection can be impaired. Unfortunately, this mean that some infectious gut microbes that can tolerate the antibiotic are then able to grow better. This explains the phenomenon of 'antibiotic-associated diarrhoea', where an infectious organism (typically *Clostridium difficile*) that is normally held in check within the microbiome becomes able to cause serious disease. Restoration of a more normal microbiota through introduction of microbial cocktails derived from the faeces of a healthy donor (known as faecal microbiota transplantation (FMT)) has been successful in treating this type of disease. There are also concerns that the overuse of antibiotics in early life (infants) might have lasting effects on the diversity of our microbiome throughout life, and with possible consequences even for subsequent generations. The evidence that this is a major health concern, however, is not conclusive. Antibiotics remain vital however in the treatment of bacterial infections and save lives.

9. The gut microbiome plays a role in the negative impact of high dietary protein and fat intakes upon health. Evidence from epidemiology also indicates that high intakes of animal protein and fat promote certain types of cancer. This is explained in part by the interactions of these dietary components with gut microorganisms. Fermentation products of protein include some compounds, such as nitrosamines and heterocyclic amines, which are genotoxic and are known to promote colorectal cancer. These compounds are formed when protein is supplied in high amounts in the diet and is not completely digested in the upper gut, causing it enter the large intestine [5]. On the other hand, high fat diets lead to the formation of excess cholesterol, which is disposed of through formation of bile acids. In the case of diets high in protein and fat, the liver disposes of these bile acids mainly by combining them with the amino acid taurine to form taurocholate that is released into the gut in the bile. In the colon, taurocholate is then metabolised by certain gut bacteria to form deoxycholate and hydrogen sulphide, both of which can promote cancer.

10. Dietary intake is clearly an important factor in obesity and its associated health problems. An increasing proportion of the populations of high-income countries, and now also of many low to medium income countries, are overweight or obese; over 60% of UK adults are in this category. Associated with this are increased risks of type 2 diabetes, heart disease and cancer. Some studies have suggested links between gut microbiota and obesity. Although the evidence in humans remains inconclusive, animal studies suggest that certain bacteria may, for example, promote fat absorption. On the other hand, there are strong reasons to think that consuming fibre as a major part of the diet can help to limit weight gain. The energy recovered from the equivalent of one gram of sugar in the form of dietary fibre is only around half of that gained from the direct absorption of one gram of mono- or dimeric sugar as often found in high sugar products such as cakes, biscuits and sweetened beverages. The reason for this is that we gain energy from fibre indirectly via microbially produced short chain fatty acids, which deliver smaller amounts of energy than the sugars themselves. Furthermore, there is evidence that some of these SCFA appear to help in controlling our appetite.

11. The overall diversity of our gut microbiome may be influenced by diet and linked to health. The overall diversity of our gut microbiome is defined by 'species richness', or by other, more complex, indices that take account of the relative abundance of all species. Microbial diversity is influenced by diet and may relate to health status. When human subjects were grouped into those with high and low diversity in their microbiome, those with low diversity were more likely to be overweight and show symptoms of 'metabolic syndrome' (a medical term for a combination of risk factors for type 2 diabetes and cardiovascular disease). Microbiome diversity and indicators of health could be restored by modifying the diet, suggesting that low diversity was the result of poor diet lacking in fibre [6].

12. Feeding regimes and birth mode play critical roles in determining the gut microbiome of the developing infant. During natural childbirth, newborn babies acquire their initial gut micro-organisms mainly from their mother's own gut microbiota. The gut microbiome of babies is however strongly influenced by the mode of birth and by early feeding regimes. Thus, babies delivered by caesarean section show a greater influence of skin and environmental organisms in their microbiomes compared to those delivered vaginally. Breast feeding encourages growth of bifidobacteria that are considered beneficial for health in helping to prevent infection by pathogenic organisms. The main reason for this is the presence of specific human milk oligosaccharides that favour the growth of certain species of *Bifidobacterium*. Babies fed from

bottles with formula milk differ in the composition of their gut microbiome, with fewer bifidobacteria. Once babies are given solid food (at weaning) their microbiota gradually comes to resemble that of adults and these earlier differences diminish [7].

13. Possibility of therapeutic interventions through dietary modulation of the gut microbiome. Certain medical conditions may be associated with alterations in the gut microbiota, for example, low populations of butyrate-producing bacteria. In the inflammatory bowel condition Crohn's disease, the normally abundant species *Faecalibacterium prausnitzii,* that has been shown to exert anti-inflammatory effects, is greatly reduced within the microbiome [8]. There is interest in finding ways to restore *F. prausnitzii* populations in these patients and one possible route is through suitable supplementation of the diet with suitable prebiotics (although these are still in development). Alternative approaches may include oral delivery of live *F. prausnitzii* cells, for example using some form of encapsulation to protect cell viability.

14. Ensuring food safety. Dangerous disease-causing organisms (food-borne pathogens) can be ingested when we eat food that has been contaminated or prepared unhygienically. These include many types of infectious bacteria (*Salmonella, Campylobacter, Escherichia coli)* that are able to survive and grow in our digestive tract. Some of these bacteria produce toxins and some are able to damage the lining of the gut and/or to invade host tissues. Consequences of infection range from diarrhoea and vomiting to severe disease including organ damage and can be fatal. These bacteria are capable of growing in the digestive tracts of other animals, which unfortunately can include farm animals such as chickens, pigs and ruminants that form an important part of our food supply. This means that unless stringent precautions are taken by the farmer and the retailer, these bacteria may be present on meat that we buy in the shops and markets. Proper hygiene procedures in animal husbandry and food production, and in food distribution and marketing, are essential for food safety. Proper food storage and cooking in the home however remain vitally important. Serious disturbances of the gut microbiota can also result from infectious agents other than bacteria that may be acquired from contaminated water, food or surfaces. These include viruses that cause diarrhoea (such as norovirus, rotavirus) and eukaryotic microorganisms such as the protozoal parasite *Cryptosporidium* and the fungus *Candida albicans*.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Identifying diets that maintain health is of increasing importance in the face of the challenges posed by pandemics, climate change and conflicting demands for land use and resources. A key element of food security is to identify what are the most appropriate food sources to promote for future production as around half of the food consumed in the UK is imported and agriculture is a major contributor to greenhouse gas emissions. Identifying crops that can be used both for human food and animal feed that can be grown and processed sustainably will be crucial. Choices between plant-based or more meat-based diets has major implications for both health and environmental benefits. Revalorisation of food waste and production of higher value co-products across the food supply chain will also be essential for a viable food production system.
- **Goal 3. Ensure healthy lives and promote well-being for all at all ages.** Following a healthy diet is one of the most important steps that an individual can take to maintain and promote their health and well-being, particularly in the longer term. Following a

healthy diet during pregnancy and ensuring that one's children eat healthily is extremely important, given the known long-term consequences of poor maternal and childhood nutrition. This includes a preference for breast-feeding over bottle-feeding in early life. In children and adults, it is important to eat a balanced diet that provides all essential amino acids, healthy fats and a variety of complex carbohydrates from cereals, fruits and vegetables that are a rich source of minerals, vitamins and other plant bioactive molecules.

- **Goal 6. Ensure availability and sustainable management of water and sanitation.** Water is the critical limiting factor in food production in many parts of the world where dietary intakes are lowest, and famine is a constant threat. Management of water resources linked to selection of the most suitable types of food production is therefore of huge importance.
- **Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all.** Some crops are increasingly being used for biofuels with the aim of reducing greenhouse as emissions. This creates competition between land use for food production and for energy production that must be carefully managed. Consideration of diets that require lower energy inputs could contribute to overall energy availability.
- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.** Agriculture, food production, processing and retailing are all essential contributors to employment and economic growth. When considering diets, foods that contribute towards a more circular bioeconomy could provide new market opportunities, as well as more sustainable production
- **Goal 12. Ensure sustainable consumption and production patterns.** Moderating meat (particularly red meat) and dairy products in our diet in favour of more plant-based foods has benefits for health but can also be more sustainable as it involves less intensive resource use (land, water and energy). Ruminant production is particularly costly and makes a significant contribution to greenhouse gas emissions Eating a wide range of plant-based foods can help with the shift away from a monocrop culture and increase agricultural biodiversity, as well as dietary diversity. Local food production is also preferable to the long-distance transportation of food, especially when this is by air
- **Goal 13. Take urgent action to combat climate change and its impacts.** Changes in agricultural production, as well as consumption patterns will be essential if we are to meet required emission targets and combat climate change The World Wildlife Fund for Nature report; 'Eating for two degrees' suggests diets that could contribute to meeting the Paris Agreement commitments. As well as benefiting the environment, these dietary changes can also benefit health. This includes eating more plants, moderating meat consumption, eating a variety of foods, and less foods that are high in fat, sugar and salt. Short supply chains can also reduce environment transport costs.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.** Seafood makes an important contribution to a healthy diet, particularly oily fish. For sustainability however it is critical to avoid over-fishing and the consequent depletion of fish stocks. Alternatives to the fishing of wild sea fish, such as fish farming can deliver environmental benefits, but risks such as pollution and infections must be carefully managed.

Potential Implications for Decisions

1. *Individual*

Most adults are free to make their own decisions on what they eat. Their choices are however influenced and/or constrained by many factors that include: affordability; availability; the influence of advertising; palatability; preparation time; available kitchen facilities; nutritional quality; advice on diet and health from news media and other forms of social media.

While packaged foods bought in shops are required to list their nutritional composition, the same is not true for unpackaged foods or for meals bought in restaurants and fast food outlets. Thus, full nutritional information is not always available to the consumer.

Children's diets are largely determined by their parents, particularly when they are young. Schools can also have a significant role through the provision of school meals and the choice of meals available.

Elderly people can have reduced olfaction and dentition and those living in care homes, especially those suffering from dementia, generally have limited choice over their meals and depend on the staff in the home.

In the end, many people do not choose the food they eat based only, or even primarily, on health and nutritional quality. Furthermore, nutritional messages (e.g. on intake of sugar, fat and protein) can often appear conflicting or confusing.

2. *Community*

Food retailers and food producers together have an overwhelming influence on the range and availability of foodstuffs.

The farming community makes decisions on what animals to rear and which crops to grow based mainly on demand and on market conditions, which are greatly influenced by choices made by large food retailers. The fishing community is also required to observe catch quotas.
The major food retailers have a huge influence on individual food choices and dietary intakes. This happens: 1) through their interactions with food producers, including stipulations on product quality, 2) through advertising, 3) through decisions on which products to stock (which may be subject to regional variation), 4) through pricing policy, including promotional offers, 5) through decisions on food production e.g. salt, sugar, fibre content of processed food, 6) through decisions on whether or not to import many foods from other countries.

The scientific research community consists of researchers working in Universities, Institutes and Hospitals as well as scientists working in Industry. Those concerned with nutrition and health investigate the health consequences of alternative dietary choices. Relevant work includes, for example, epidemiology, dietary intervention studies, gut microbiology, immunology and metabolite profiling. Findings that provide information of the safety and health outcomes of different food choices are published in the scientific literature and presented at meetings. This new information then becomes available to the food industry, the media, regulatory bodies and ultimately the individual consumer to help inform food choices.

Several organisations exist to promote the exchange of information and ideas between academics and the food industry. These include, for example, BNF (the British Nutrition Foundation), ISAPP (International Society for Probiotics and Prebiotics) and ILSI (International Life Science Institute).

The 'information community' includes print, broadcast and other forms of social media. This is the immediate source of most people's information on diet and health and therefore has a huge influence on their behaviour.

3. *National*

Multiple advisory panels consisting of scientists and nutritional experts exist to advise Governments, Industry and the Public on policy and regulations with respect to food and health. One important responsibility is for food safety and the vetting of proposals to introduce new (novel) types of food or food production processes into the commercial market. A more general responsibility is for nutritional advice to Government on such issues as the desirability and need for fortification of foods (e.g. with folate) or taxes on sugar and fat. It is recognised that nutritional recommendations can contribute to preventative medicine by potentially reducing the load from diabetes, heart disease and cancer.

Government decisions have an enormous impact on food production and quality. They determine:

- regulations on food labelling, packaging and marketing
- regulations on food safety at all stages in the production, processing, transportation and sale of foodstuffs ('from farm to fork')
- regulations on environmental standards and sustainability applied to food production (agriculture and fishing)
- regulations on animal welfare relating to food production
- internal taxation regimes (e.g. for alcohol, sugar, fat)
- external tariffs applied to food and agricultural products
- trading arrangements with other countries that determine the quantity and quality of imported food

Pupil Participation

1. *Class discussion of issues associated with diet, health and the gut microbiome*

Consider the food swaps suggested in the WWF Livewell 'Eating for Two Degrees' report. Look for evidence on how these swaps might impact on the gut microbiome (consider pro- and pre- biotic activity, as well as any important nutrients and other bioactive molecles that the foods contain) and whether these would benefit or be detrimental to our health.

2. *Pupil stakeholder awareness*

Construct a map from 'farm to fork' of all the actors in the food supply chain. For each step consider 'barriers' and 'opportunities' to make food production more healthy and sustainable.

3. *Exercises*

a. Identify currently marketed pre- and probiotics. For each probiotic identified, what bacteria are present and how are the supposed to benefit our health. For the prebiotics, describe their composition and find out as much as you can about how they are supposed to impact on our gut health.

b. Each pupil should list about as many foods as they can that are considered to be healthy. Once they have this list sort on a whiteboard into categories; 1. Produced Locally 2. Not Produced Locally. For category 2. (Not Produced Locally) consider why they are not produced locally, who would need to be involved for them to be produced here and whether they could be substituted with a similar product which could be grown locally.

c. Then list as many foods as you can that are considered unhealthy. Once you have these, think about ways in which they could be made healthier for us (with regard to the gut

microbiome) and for the planet (sustainable production) and who would need to be involved across the food supply chain to make it happen.

This should build on information obtained through class discussion and stakeholder awareness.

The Evidence Base, Further Reading and Teaching Aids

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WWF Livewell Report; Eating for to degrees.

Glossary

Anaerobe. A microorganism that is able to grow in the absence of oxygen ('obligate anaerobes' only grow when oxygen is low, while 'facultative anaerobes' can grow with or without oxygen)
Dietary fibre. Components of the diet that remain undigested in our upper intestine (stomach and small intestine) and become available for fermentation by the microbes inhabiting the large intestine.
Disaccharide. Carbohydrate consisting of two monosaccharide sugars joined together (e.g. sucrose, maltose)
Epidemiology. Study of the occurrence and spread of diseases within different populations of animals and plants
Fermentation. A process by which energy is gained in the absence of oxygen. In anaerobic gut bacteria, this generally results in the production of short chain fatty acids from carbohydrates and proteins.
Genotoxic. Causing damage to the genetic material (DNA)
Gut microbiome/ Gut microbiota. The community of microorganisms that is present within our digestive tract.
Monosaccharide. Single sugar molecule, typically a ring structure containing 6 carbons (e.g. glucose, fructose).
Mucus. Slimy secretion composed pf protein and carbohydrate that is produced by cells lining the gut (and other surfaces in the body). Has protective and lubricating roles.
Oligosaccharide. Carbohydrate consisting of three or more monosaccharide sugars joined together, but still small enough to dissolve in water.
Pathogens (pathogenic). Organisms that can cause disease.
Phylum (pl. phyla). A high-level grouping of life forms that share certain characteristics - used for the purposes of classification (taxonomy).
Prebiotics. Compounds added to the diet that are considered to encourage beneficial microbial species or activities in the gut.
Probiotics. Live microorganisms present in the diet that are claimed to be beneficial for health. Most are delivered in fermented foods such as 'live' yoghurts.
Short chain fatty acids (SCFA). Acids that carry a carboxyl (COOH) group with the general formula $C_nH_{2n}O_2$ (n typically than 6 or less). Major acids from the microbial fermentation of fibre in the gut are acetic (C_2), propionic (C_3) and butyric (C_4)
Synbiotics. Refers to combinations of a prebiotics and probiotics.
Therapeutics. Compounds or microorganisms that have the potential to improve or restore health.