Global Diet and Health

What should I have for lunch?

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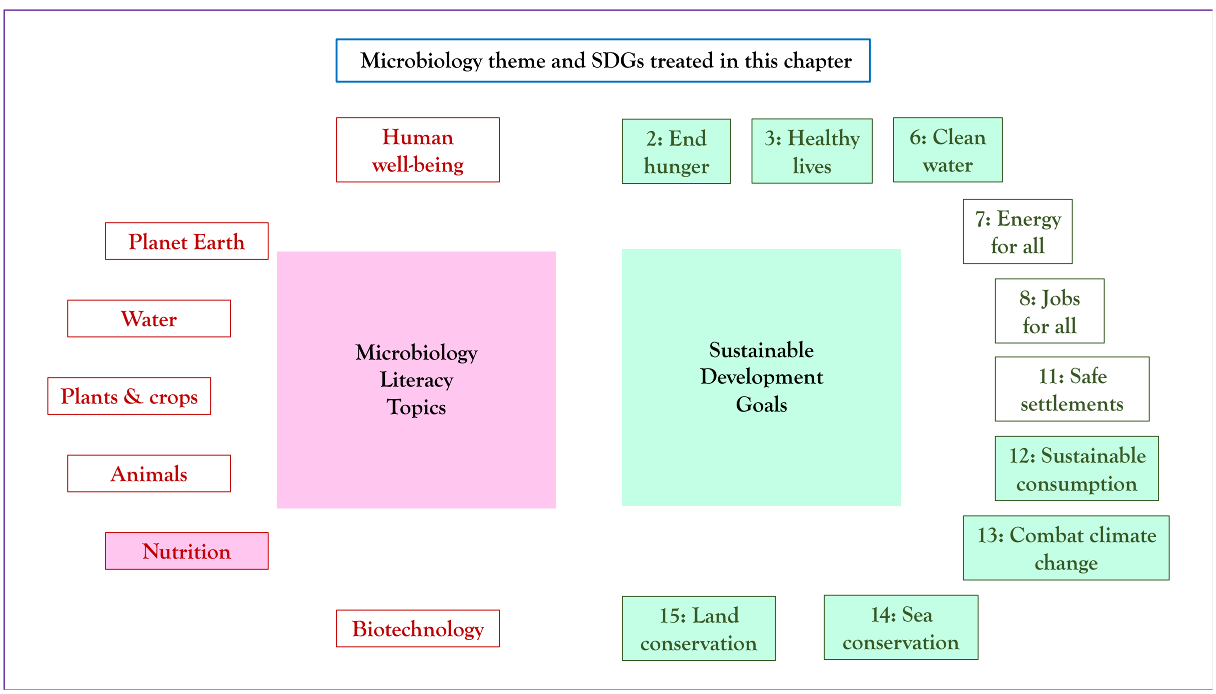
Storyline

Many of us have to choose what to eat multiple times per day. Although the foods we consume affect our health in many ways, we choose food based on non-health criteria such as taste or availability. When health is considered, it is often in the context of meeting nutritional needs (e.g. quantifying energy, macronutrients, and micronutrients). However, a complex community of microbes in the gut interact with the foods we eat, affecting nutrition but also other aspects of our health. Gut microbes can improve food digestibility, but the types of foods we consume and the practices we use to produce and prepare our foods also impact which gut microbes can survive in the gut. The molecules gut microbes produce as part of their daily processes, including breaking down different parts of our diets, affect things like how much fat we store in our bodies, how easily we can fight off infections, and how much stress or anxiety we feel. Ideally, we would choose what to eat based on an understanding of these dynamics, picking foods that support a gut microbial community that helps us stay healthy. Nevertheless, there is still much to learn about what types of gut microbes promote which aspects of health and what diets support those gut microbes. Also, food choice is often constrained by culture, politics, and economics. Therefore, supporting a healthy microbiota by exercising food choice is closely related to multiple sustainable development goals.

Microbiology and Societal Context



The microbiology: microbial degradation of dietary fiber and toxins; dietary diversity, food type, and food preparation affect metabolism, immunity, and behavior by altering gut microbiota function; efficacy of prebiotics and probiotics; resistance to and treatment of microbial imbalances due to diet, infection, antibiotics; food supply chains affect environmental microbial communities. *Societal Context:* integrating the gut microbiota into food security pillars (availability, access, stability, utilization, preference). *Sustainability Issues:* hunger; health; sanitation; production and consumption; climate change; conservation of terrestrial and marine/aquatic environments.

Global Diet and Health: The Microbiology

1. ***How does food support health?*** Bodies require macro and micronutrients to support everyday activities like growth and activity. Different foods provide different nutrients for the body (see tables 1-3). For example, grains such as rice, flour, and corn, have a high carbohydrate content that serves as fuel for the body. Some nuts have high-fat content that our bodies store as sources of energy for times when it is hard to find food. In addition to macronutrients (fats, nucleic acids, protein, and carbohydrates) (table 1), our diet also contains micronutrients, such as vitamins and minerals, that we cannot produce within the body (see table 2-3). For example, animal products are high in iron, which helps our blood transport oxygen throughout the body. Calcium, found in many dairy products, is required for bone strength. Sodium from salt is used by the brain to send messages throughout the body.

The human body has enzymes that allow it to degrade and absorb macronutrients in food. However, foods also contain indigestible compounds such as fiber and plant toxins that can interfere with these processes. Microbes in the digestive tract, known as the gut microbiota, help degrade these compounds and improve food digestibility either by producing energy from fiber or by detoxifying plant compounds. The products these microbes make can also affect host fat storage, defense against infections, susceptibility to allergies, and responses to stressful situations. Diet-microbe interactions can therefore impact human health beyond nutrition.

2. ***How does diet composition vary globally?*** Different diets meet nutritional needs in different ways. While carbohydrates are often dietary staples, the carbohydrates themselves can be interchangeable. With the expansion of global food trade, many populations now consume large amounts of corn, wheat, and rice. However, depending on the climate, soil composition, and historical foodways, people living in different parts of the world may be more likely to consume one carbohydrate over another. For example, wheat flour was historically cultivated throughout Europe, and as a result foods like bread and pasta are consumed widely throughout Europe. On the other hand, countries in East Asia have historically relied on rice as a staple grain, and consequently, their diets prominently feature rice-based dishes. Even within global populations with similar dietary habitats, variation in what people eat on a day-to-day basis results in different intake of macronutrients, fiber, and toxins. As a result, both local patterns in diet, as well as individual dietary preferences and restrictions, influence and shape the composition of the gut microbiota. For example, individuals who eat vegetarian diets have a larger proportion of bacteria, such as *Bacteroidetes,* that process the fibrous material of plant-based foods. Whereas individuals who consume more animal-based diets, such as meats and cheese, have more lactic acid bacteria. These different microbes have different health impacts on people.

3. ***What is the relationship between food preparation and microbes?*** Food preparation serves two main functions. First, it preserves food so that it can be safely used for a longer duration of time. Cooking, smoking, and fermenting transform foods in ways that delay the rotting process that is driven by microbes in the environment. Second, food preparation affects how food is utilized by our bodies. For example, it can make foods more digestible by eliminating fiber and toxins.

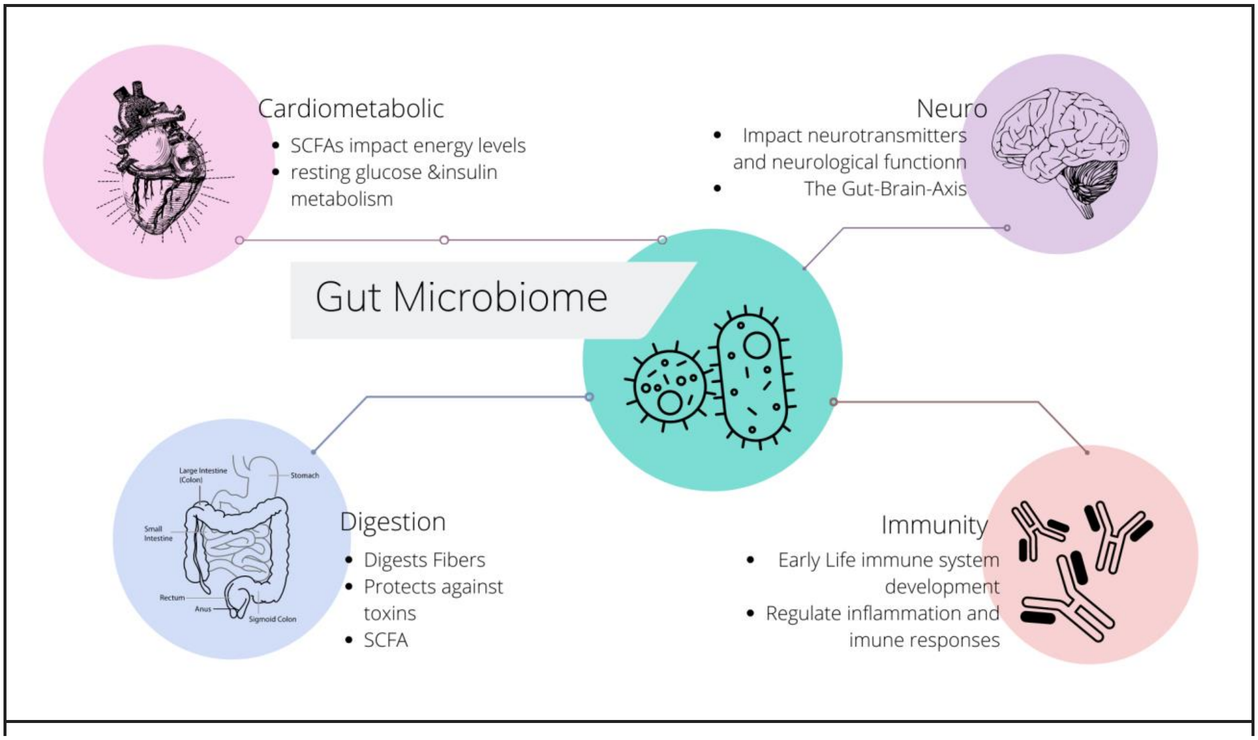
Fermentation is one of the most commonly used food preparation methods globally. It uses certain types of microbes to degrade macronutrients in food, like carbohydrates. These microbial actions generally make the food easier to digest and more nutritionally valuable. Also, during this process, the microbes create short-chain fatty acids (SCFAs) that prevent other types of microbes from growing. This protects the food from rotting and results in fermented foods containing a very specific community of live microbes. Interestingly, fermented foods created from the same foods but using different culturally-informed fermentation methods have different effects on the gut microbiota.

4. ***How do diet-microbiota interactions impact our health?*** Different diets are linked to specific health outcomes and diseases. For example, an industrialized diet that is high in fat and protein and low in fiber has been associated with an increased prevalence of cardiometabolic diseases like obesity worldwide. Although macronutrient intake and activity levels may contribute to these patterns, they do not explain the majority of the disease cases observed, nor do genetics. There is growing evidence that microbes mediate the associations between diet and health outcomes. For example, the SCFAs produced when microbes degrade dietary fiber can be used by hosts as an energy source. While this energy source is helpful to hosts in some situations, if hosts get more energy out of their diet than they use in their daily activities because of microbial SCFAs, this can contribute to weight gain. Perhaps more importantly, SCFAs can signal host body systems and directly change processes like fat storage and glucose regulation. Different types of SCFAs therefore can positively or negatively affect metabolic health.

Variation in the gut microbiome can also affect the immune and nervous system development and function. The gut microbiome trains the immune system in early life and helps regulate responses to infection in later life. Microbial metabolites help tell different parts of the immune system when to react. For example, SCFAs are generally believed to be anti-inflammatory, which is good for health. The gut microbiome can also metabolize hormones and neurotransmitters and appears to influence the stress response. Therefore, if diet alters the types of microbes in the body, it can have widespread health consequences.

What defines a healthy microbiome is an active area of study. However, more diverse microbiomes are believed to be more resistant to invasion by pathogens and provide more potentially beneficial services to hosts. It also means that multiple types of microbes provide the same service to their hosts so losing one doesn't change how the overall community functions. Expressed another way, the more diverse our microbiome is, the more resilient it is to stresses such as infections and medicament therapies that have the potential to cause long-lasting, sometimes harmful changes – *dysbiosis* – in our microbiota (see below). It is also believed that certain groups of microbial taxa and/or functions may act as 'keystone' taxa or genes that are disproportionately influential in shaping overall community function.

Variation in diet that can affect health through microbial pathways occurs throughout life. Length of breastfeeding as well as the types of weaning foods that babies are introduced to can alter the microbiome, leading to consequences for the development of multiple body systems. The microbiome is most sensitive to change in early life (< 3 yrs of age) when it is developing. However, despite increased stability later in life, the microbiome can still be substantially impacted by changes in diet.

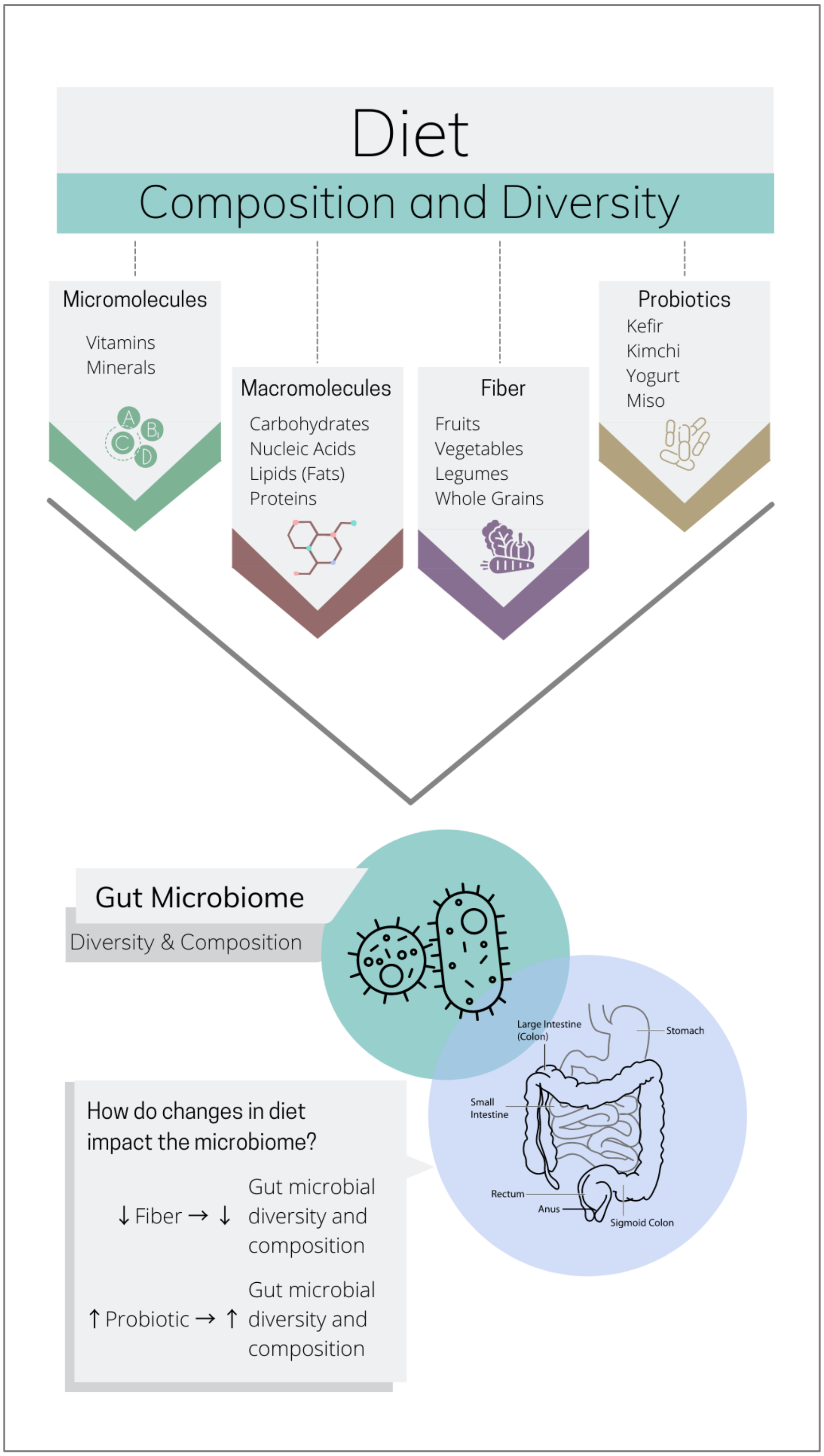


The impact of the microbiome throughout the body.

5. ***Are there microbial superfoods?*** Because diet-microbiome interactions have such substantial impacts on health, there is interest in identifying microbial superfoods that can promote health. Prebiotics and probiotics are most often considered. Prebiotics are foods that provide material for specific microbes to degrade, thereby supporting their survival. Fiber is a common prebiotic. In contrast, probiotics are foods that contain live microbes that can potentially colonize the host that consumes them. Yogurt and Kefir are often presented as examples of probiotic foods. In fact, fermented foods such as yogurt and kefirs are technically both pre-and probiotics.

Despite the excitement around the potential for prebiotics and probiotics to positively influence health, current research on this topic is limited. While some studies suggest prebiotics and probiotics can positively affect health (from improving gastrointestinal, or GI, infections to reducing the symptoms of depression), others have shown that most do not affect microbiota composition and function in the long term.

In addition to trying to identify single foods that have beneficial impacts on the microbiota, researchers believe that certain diet patterns may positively affect the microbiota and health. For example, high-fiber fruits and vegetables are likely to promote a diverse microbiota that is likely to have positive health impacts. Fiber also supports microbes that degrade fiber to produce SCFAs, which can benefit many aspects of health. Further, eating a diverse diet appears to result in a diverse microbiota. Knowledge of whether the diversity in food types themselves versus macro- or micronutrients is most important in maintaining gut microbiome function is still being built.



6. ***What factors disrupt diet-microbe interactions?*** Disruptions to the gut microbiome can result from a variety of factors. First, waterborne illness is a serious problem in many human populations with limited access to clean water. GI infections that are initiated by consumption of unclean water have been shown to interact with diet and genetics to create different types of malnutrition in infants and children. Even in adults, however, a serious GI illness can substantially alter the microbiome.

The antibiotics used to treat GI illness can ironically contribute to more illness. Antibiotics do not target only pathogens. Therefore, antibiotics reduce microbial diversity in the gut overall and provide pathogens with an improved opportunity to establish themselves as more resources become available in the community. These dynamics are the reason that antibiotic treatments for GI illness are often of limited efficacy. Similarly, antibiotic consumption for other, non-gut infections can have a strong effect on the microbiota and lead to other health issues.

Finally, diet itself can lead to disruptions in the microbiome. Some foods, such as honey and ginger, have antimicrobial properties. Additionally, high consumption of industrially produced foods, which tend to be low in fiber, and high in sugar and fats, has been associated with reduced microbial diversity and SCFA production.

7. ***How do global food supply chains affect the microbiota?*** Changes in technology, labor, and population dynamics have led to changes in food practices and landscapes across time and space. Technological upgrades to farming have led to the industrialization of agricultural practices. The resulting large-scale agriculture utilizes fertilizers and pesticides to maximize output. While these practices increase the yield, they also present a risk of environmental pollution and alteration of the environmental microbial ecosystem. For example, nitrogen-fixing bacteria have a complex symbiotic relationship with certain plants, such as legumes, and fertilizers and pesticides disrupt these bacteria. The loss of nitrogen-fixing bacteria puts plants at risk since the bacteria are fundamental to plant nutrition. It can become more difficult to grow certain foods without these bacteria, which can feedback to alter diet and health. Additionally, reduced environmental microbial diversity can affect human health directly. Contact with environmental microbes increases human microbiota diversity and has positive immune impacts. Less diverse environmental microbial communities will be less likely to provide these benefits and leave humans more vulnerable to poor health.

Large-scale industrial livestock and fisheries operations have created similar risks. One widespread concern is the production of methane by livestock and its contribution to climate change. Reducing the scale of these operations or even manipulating the microbiota of livestock to produce less methane would mitigate some of these risks. Further, these large-scale operations often rely on using antibiotics on healthy animals to reduce the risk of infection and accelerate growth. However, misuse and overuse of antibiotics in animals without infection creates an overabundance of antibiotic-resistant bacteria. Such bacteria serve as reservoirs for the transfer of resistance to pathogens – of food animals and of humans – which can survive antibiotics and are not easily treated if they cause infection. As a result, both the loss of microbial diversity associated with food animals as well as the risk of increased antibiotic resistance that these practices cause represent serious microbial risks to human health. As such, the non-clinical use of antibiotics in food animal husbandry is an important consideration of *One Health* approaches to improving public health. Efforts to integrate more sustainable and environmentally friendly methods to produce food will ultimately benefit human health.

Large-scale agriculture and global food networks have also led to a loss of local heritage diets and foods. The loss of heritage diets can be attributed to many factors including, but not limited to, changes to labor patterns, the market value of heritage foods, and NGO/development programs. Fast-paced lifestyles and work/school hours have made industrially produced foods more accessible and viable for day-to-day consumption. In other cases, economic policies and trends have made it so heritage crops are unsustainable on a local scale and must be grown for export. In addition to the loss of cultural practices associated with heritage foods, there is also likely a loss of gut microbiota diversity. The variety of macronutrients, micronutrients, fiber, and toxins contained in heritage foods is not well replicated in large-scale food operations. Without this diversity in food composition, gut microbiota diversity can become quickly depleted.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 2. Zero hunger.** The gut microbiota is an active contributor to digestion and nutrient uptake. Protecting gut microbial diversity promotes good nutrition and overall health. Additionally, plant and animal microbiomes can be harnessed to maximize food outputs and increase the availability at multiple levels (community, and global).
- **Goal 3. Good health and well-being.** A healthy diet will positively influence health both indirectly and via the microbiota. The incorporation of fresh fruits and vegetables and other high-fiber foods is likely to benefit the microbiome, protecting hosts from both infectious and chronic disease.
- **Goal 6. Clean water and sanitation.** The food supply chain affects clean water supplies and sanitation chains. Fertilizer runoff can contaminate waterways, and waterborne pathogens can establish in food production facilities that do not engage in sufficient hygiene practices. Early life GI infections are associated with early-life malnutrition and other negative outcomes, making clean water a critical health and microbiota issue.
- **Goal 12. Responsible consumption and production.** Engineering projects that feature the alterations to the plant and animal microbiota contribute to efforts to reduce hunger through sustainable and environmentally friendly food production. Supporting smaller-scale farming practices can also promote the production of more diverse foods, including heritage foods, that will increase microbiota diversity in local populations consuming the foods.
- **Goal 13. Climate action.** Climate action often involves massive changes to farming practices that increase the efficiency of space use and reduce fertilizers and pesticides that can run off and contaminate water and other food resources. Microbial inputs into nutrient cycles are also essential and may become more important as climates become more challenging for plants.
- **Goal 14. Life below water**. Sustainable fisheries practices will reduce disruptions to marine wildlife and ecosystems. Maintaining healthy marine ecosystems will lessen harmful bacterial processes such as algal bloom. Sustainable fisheries practices will also ensure food security to communities that depend on small-scale fisheries.

- **Goal 15. Life on land.** Proper farming and agricultural practices preserve land integrity. This includes maintaining the biodiversity of microbial communities and preventing the rise of antibiotic-resistant bacteria.

Potential Considerations for Decisions

1. ***Individual***
   a. Dietary macronutrient content
   b. Dietary impact on the microbiota
   c. Dietary preferences and restrictions
   d. Food availability/accessibility

2. ***Community policies***
   a. Local environmental consequences (pollution of public spaces and local water bodies with faeces, nitrogen, phosphorus), provision of clean drinking water,
   b. Health costs associated with chronic disease
   c. Non-microbial parameters: support of local businesses
   d. Formation of lifelong eating practices
   e. Private sustainable community food initiatives (local gardens)
   f. Public food support programs (food stamps, food banks, elimination of food deserts)

3. ***National policies***
   a. Public food support programs (food stamps, food banks, elimination of food deserts)
   b. International Development
   c. Public subsidization of good food production practice
   d. Disease burdens and financial costs
   e. Environmental pollution
   f. Ensuring safe drinking water supplies
   g. Greenhouse gas production and climate change
   h. Eutrophication/algal blooms/toxic algal blooms preventing the use of surface water bodies, fisheries, tourism, etc.

Pupil Participation

1. Class discussion of the relationship between food production, diet, the microbiota, and health.

2. Pupil stakeholder awareness

a. Maintaining a healthy microbiome has several positive contributions to SDGs. Which of these are most important to you personally/as a class?

b. How do local culture and policy shape the microbiome through its impacts on diet?

c. Can you think of anything that might be done to reduce the possible negative consequences of globalization on diet and the microbiome?

3. Exercises

a. If you were to design an ideal diet for your microbiota, what would it be? How easy would it be to eat that diet?

b. Brainstorm some small things (within your means) that you can do to support your microbiome?

c. What is an experiment you would design to test the link between a certain part of diet and the microbiota? Health?

Tables

Table 1: Macronutrients		
Macronutrient	**Type**	**Dietary Sources**
Carbohydrates	Simple (monosaccharides, disaccharides) Glucose, fructose (mono-) sucrose, lactose (di-)	Fruits, dairy, processed/refined foods
	Complex (polysaccharides) Starches, fiber, glycogen	grains, leafy greens, legumes, corn
Lipids	Unsaturated (liquid at room temp)	Olive oil, fatty fish, nut oils, nuts
	Saturated (solid at room temp)	Meets, butter, plant oils, dairy
	Transfat (semi-solid at room temp)	margarine, baked/fried goods
Protein	Animal and plant proteins	Beef, chicken, egg, dairy, etc. (animal) Soy, chickpea, pea (plant)
Nucleic Acids	Nine AA that can't be made by the body and are essential for growth and maintenance: Histidine, Isoleucine, Leucine, Lysine, Phenylalanine, Threonine, Tryptophan, Valine	Organ meat (liver), Fish,

Table 2: Micronutrients - Vitamins		
Name	**Role**	**Foods**
A (retinol)	Bone formation, vision	Cheese, eggs, oily fish, fortified low-fat spreads, milk and yogurt, and liver.
C	Collagen production, iron absorption	citrus fruit, peppers, strawberries, blackcurrants, broccoli, brussels sprouts, potatoes.
D	Bone formation	oily fish, red meat, liver, and egg yolks.
E	Absorption and storage of vitamin A, antioxidant	Plant oils, nuts, seeds, and wheat germ.
K	Bone formation	green leafy vegetables, vegetable oils, cereal grains
B (B_1, B_2, B_3, B_5, B_6, B_{12})	Build and release energy, Build and produce proteins, cells, and collagen.	Peas, some fresh fruits, nuts, wholegrain bread, and liver.
Folate/Folic Acid	Metabolize amino acids	Broccoli, brussels sprouts, leafy green vegetables, peas, chickpeas, kidney beans, liver.

Table 3: Micronutrients - Minerals		
Name	**Role**	**Foods**
Calcium	Bone formation and strength	milk, cheese and other dairy foods, green leafy vegetables
Phosphorus	Bone formation, bone strength	red meat, dairy foods, fish, poultry, bread, brown rice, and oats.
Potassium	Osmoregulation, neuro impulses	Bananas, some vegetables, beans, nuts, seeds, fish, beef, chicken, turkey.
Sodium	Osmoregulation, neuro impulses	Salt, ready meals, meat products, cheese, and savory snacks.
Chloride	osmoregulation	Salt, ready meals, meat products, cheese, and savory snacks.
Magnesium	Bone formation	Spinach, nuts, wholemeal bread.
Iron	Hemoglobin-O2 transportation	Liver, red meat, beans, edamame beans, chickpeas, nuts, dried fruit, soybean flour
Zinc	Coagulation cascade	Meat, shellfish, dairy foods, bread, wheatgerm
Iodine	Thyroid regulation	Sea fish, shellfish
Flouride	Bone strength and prevents tooth decay	Water

The Evidence Base, Further Reading and Teaching Aids

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Educational Videos:

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https://www.gutmicrobiotaforhealth.com/bacteria-rule-over-your-body-how/
https://www.youtube.com/watch?v=1sISguPDlhY

Glossary

Antibiotic: A compound, either natural or pharmaceutical, that prevents microbial growth.
Antibiotic-resistant bacteria: Bacteria that have, through mutations and evolution, developed a tolerance to specific antibiotics.
Fermentation: Food and drink preparation processes that use microorganisms, such as bacteria and yeast, to break down carbohydrates, usually sugars and starches, into lactic acid or alcohols. Functionally, this process increases the shelf-life of foods.
Gut Microbiome: The collection of microorganisms and their genes living in a host gut.
Gut Microbiota: The collection of microorganisms that inhabit the gut. In the context of this framework this refers primarily to bacteria living within the gut.
Heritage diet: A diet that has historical and cultural significance to a particular community or region.
Keystone taxa: A collection of a specific type of microbe that shapes the overall structure and function of the microbial community.
Keystone genes: Specific genes that shape the overall structure and function of the microbial community.
Macronutrients: Basic units of food that are required by the body for growth, development, and maintenance. The four macronutrients are carbohydrates, proteins, lipids, and nucleic acids. *See table 1*
Micronutrients: In this text micronutrients specifically refer to vitamins and minerals. Both vitamins and minerals are considered essential nutrients for growth, development, and maintenance. *See tables 2 and 3*
Minerals: Inorganic elements which are essential for growth, development, and maintenance. *See table 3*
Prebiotics: Any substance that promotes the growth of microbes within an ecosystem. e.g.: fiber from leafy vegetables.
Probiotics: Any substance that contains live and active colonies of microorganisms that can add to the population of an ecosystem. e.g.: kefir, kimchi, sauerkraut, etc.
Short-chain Fatty Acids (SCFA): Fatty acids (a chain of carbons ending with a carboxyl group) with chains of fewer than 6 carbons atoms. Most commonly cited and studied are: acetic acid, propionic acid, and butyric acid
Sustainable Development Goals (SDGs): 17 goals set proposed by the United Nations to create a "better and more sustainable future for all" by the year 2030.
Symbiotic: A relationship in which all parties mutually benefit from their close associations.
Vitamins: Organic substances which are essential for growth, development, and maintenance. E.g.: vitamin A, vitamin B, folate/folic acid, etc. *See table 2.*