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FROM SOIL TO STOMACH: THE JOURNEY OF MICROBES IN FOOD

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Did you know the yogurt you eat is made by tiny living things called microbes? Have you ever seen mold on bread? That is a microbe at work, too! Microbes are everywhere in the food system—from soil and water to crops, animals, and even our own bodies. Some microbes spoil food or make people sick, but others help plants grow, support digestion, and turn milk into cheese or dough into sourdough bread. This article explores how microbes move through the food system and what they do along the way. Scientists are using powerful laboratory tools to figure out which microbes are present, what jobs they do, and how we can support the helpful ones. By guiding microbes in the right direction, we can grow healthier crops, waste less food, and protect both people and the planet. From soil to stomach, everything is connected—and microbes play a big role in keeping the system working!

FOOD MICROBES: THE GOOD AND THE BAD

MICROBES

Tiny living things such as bacteria, fungi, and viruses. They are everywhere (soil, water, food, and even our bodies) and can be helpful or harmful.

FOOD SYSTEMS

The various environments and associated activities involved in getting food to your plate, including the production, transport, processing, and selling of food.

MICROBIOME

A community of microbes and associated components (e.g., proteins and DNA) located in a certain place, like in soil, plants, animals, or humans.

Chances are, you already know a few things about **microbes** and food. You may have been taught to wash vegetables before making a salad, or maybe you had to throw out some nasty-smelling, moldy leftovers that were left in the fridge too long. Certain microbes can make you sick or cause food to spoil. But maybe you have also eaten yogurt, cheese, or sourdough bread. These foods are made using harmless microbes that help turn raw ingredients into healthy, tasty foods.

What you might not realize is that food-related microbes are a natural, and sometimes critical, component of *every part* of the **food system**. Each step in food production—from soil and water, to crop plants and farm animals, to our own bodies—has its own **microbiome** [1]. A microbiome is like a tiny neighborhood of microbes living together in a particular place, like in the soil or in your gut. Food system microbiomes are constantly interacting—with each other, with their environments, and with us (Figure 1). Some of those microbes do good things, like helping plants grow or improving digestion. Others do harm, like causing diseases, damaging crops, or polluting water. The balance between helpful and harmful microbes can shape everything from how much food we can grow to how much of it gets wasted (Figure 2).

HOW DO SCIENTISTS STUDY FOOD MICROBIOMES?

Scientists are working to understand which microbes are present in food microbiomes, how microbiomes in different parts of the system affect each other, and how we might be able to guide or change microbiomes to protect crops, reduce the amount of food that is wasted, improve food quality, and keep people and the planet healthy [2].

HIGH-THROUGHPUT DNA SEQUENCING

A scientific method that, based on the analysis of genetic material, can be used to identify the types and proportions of microbes present in an environment.

Each sample of soil, food, or water contains thousands of different kinds of microbes—many so similar looking that they are hard to tell apart using a microscope, and many that cannot even be grown in the lab. One tool that scientists use to study these complex communities and figure out which microbes are present is called **high-throughput DNA sequencing** (Figure 3A). This technique can quickly read tiny pieces of the genetic material from *all* the microbes in a sample at once. The result is like a fingerprint: a pattern that shows which kinds of microbes are present and how many of each kind are there. Also, by comparing samples collected at different times or places, scientists can see how microbiomes change, and they can use that information to develop strategies that support helpful microbes or reduce harmful ones.

Figure 1

Microbes connect all parts of the food system (connections shown by blue arrows), and they are continuously interacting. Microbes from the soil get into plant roots, stems, and leaves. When farm animals eat plants, they eat their microbes too. Healthy microbes help animals digest their food. When farm animals poop, microbes return to the soil through manure. Animal and plant microbes reach us when we eat animal products or fruit/vegetables. Humans can change food system microbes by adding compost to the soil, giving antibiotics to farm animals, or using special microbes that can help crops grow (called biofertilizers) or protect crops from pests (called biopesticides).

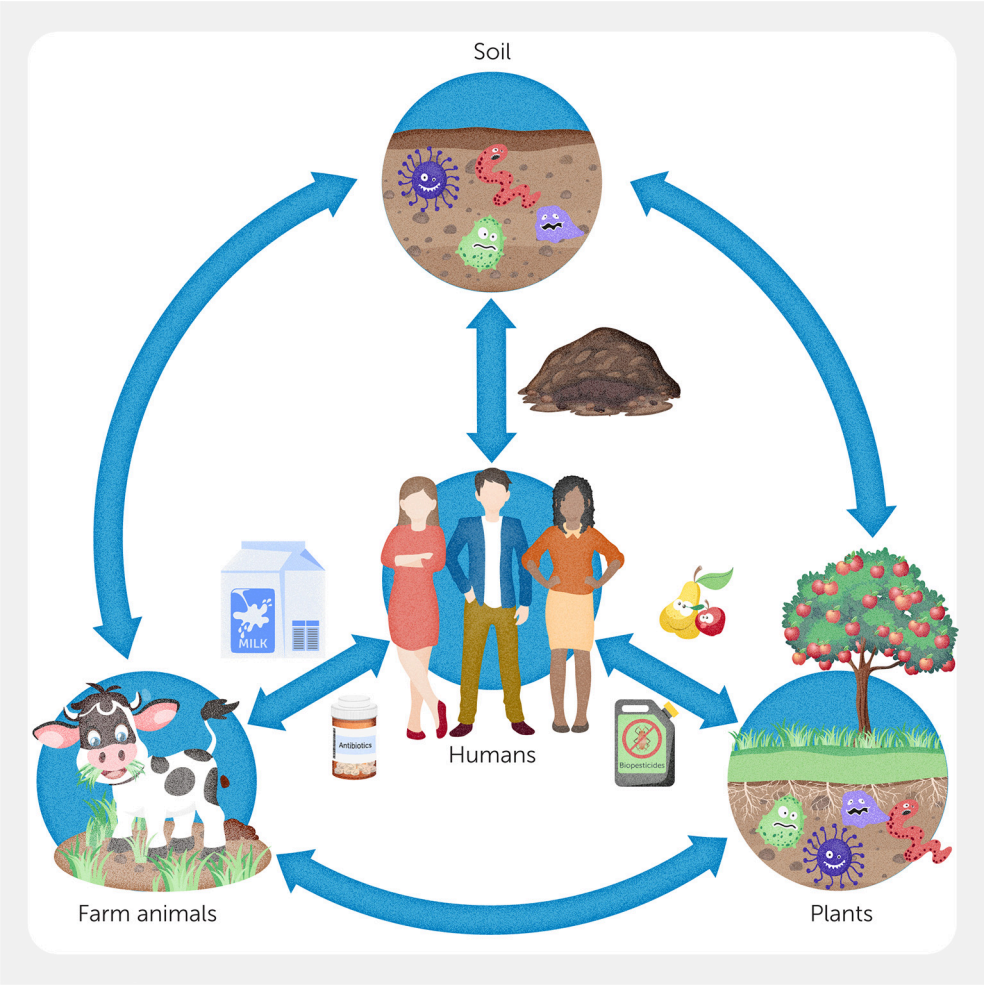

Figure 1

FROM THE GROUND UP

If you want to understand where food begins, look down. The journey often starts in the soil.

Soil is not just dirt—it is alive with billions of microbes that make up the soil microbiome. Some of these microbes break down dead plants and animals, turning them into nutrients that crops can use. Others form partnerships with plant roots, helping the plants absorb water and nutrients or survive tough conditions like drought or salty soil. For example, certain microbes help legumes (like beans, peas, and lentils) pull nitrogen from the air, giving the plants a natural boost without the need for chemical fertilizers [3].

Soil can also contain harmful microbes that cause plants to rot, wilt, or grow poorly. If the soil has too few good microbes, or too many harmful ones, unhealthy crops and poor harvests can result. Microbes from the soil often become part of the plant's own microbiome, ending up on leaves or stems or even inside plant tissues. In fact, many

Figure 2

"Helpful" food system microbes do good things, like helping plants produce lots of fruits and vegetables or reducing the amount of methane produced by farm animals. Harmful microbes can cause diseases in plants, animals, or humans, damaging crops and leading to lower production of milk, eggs, or meat. The balance between helpful and harmful microbes can shape everything from how much food farmers can produce to how much food spoils before it can be eaten.

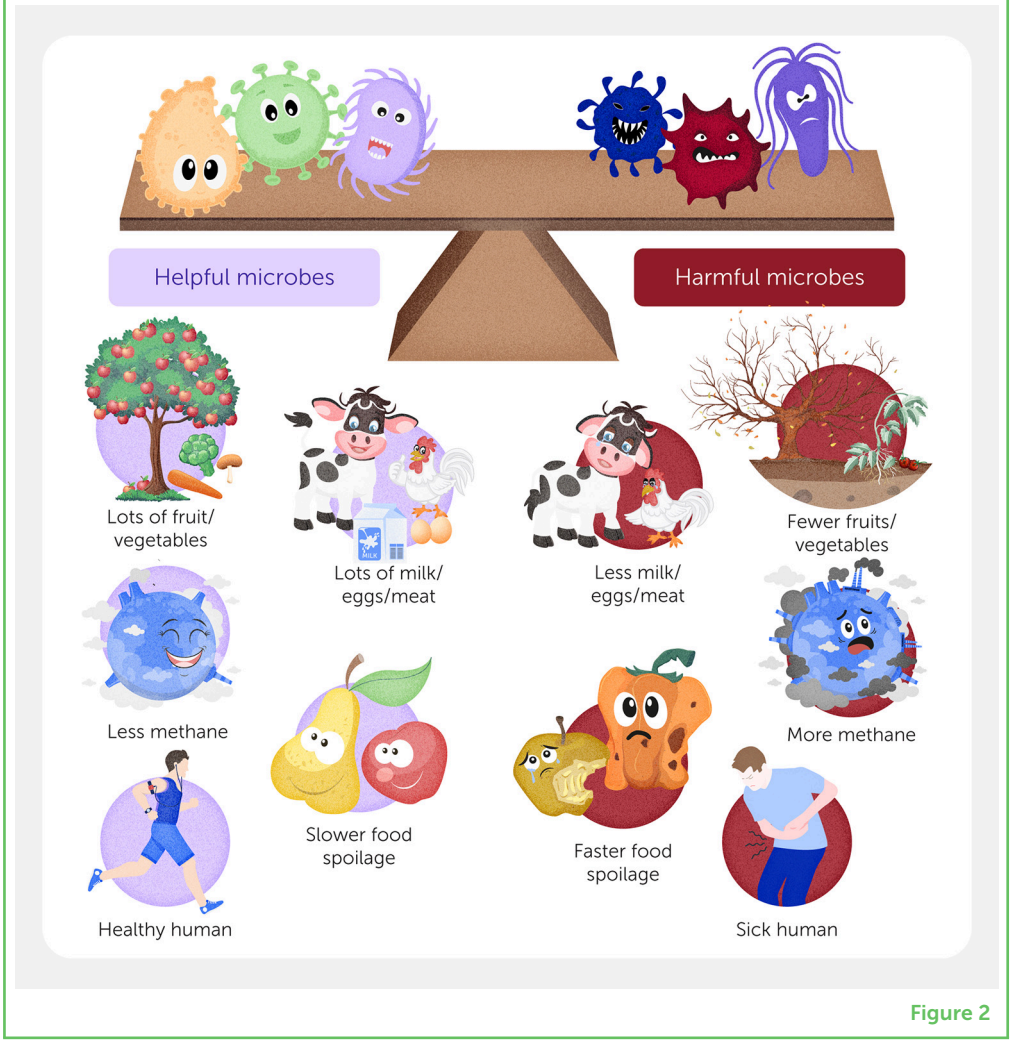

Figure 2

of the microbes found on fresh produce come directly from the soil. When people eat raw fruits and vegetables, they can also ingest these microbes. Some are harmless or even helpful, while others, especially those grown in contaminated soil, can cause disease, which is why we should wash raw fruits and vegetables before eating them.

The soil microbiome connects to farm animals through plants. When cows, sheep, or other livestock eat plants, they take in the microbes living on those plants along with the nutrients the plants provide. Later, when the animals leave behind manure (poop), their own gut microbes re-enter the environment and can become part of the soil once again. This cycle can be helpful, adding nutrients and "good" microbes to the soil, but it can also spread harmful microbes or bacteria that have become resistant to **antibiotics**. This means antibiotics no longer work as well to kill those resistant bacteria, which can make infections in people and animals harder to treat.

ANTIBIOTICS

Chemicals that kill bacteria or slow their growth. They are used in medicine to treat and cure diseases caused by bacteria.

To make food safer and to grow stronger crops that produce more food, scientists are exploring ways to guide the soil microbiome on

Figure 3

(A) To study the communities of microbes in the various parts of the food system, scientists start by collecting samples (of soil, for example). Samples are studied using high-throughput DNA sequencing, to show which kinds of microbes are present and how many of each kind are there. **(B)** Humans have learned how to "tip the scale" toward good food system microbes by adding helpful microbes to soil or silage, making fermented foods that last longer or have health benefits, or by ingesting good microbes—called probiotics—to support gut health.

purpose—by adding helpful microbes to seeds or soil or changing how fields are cared for (Figure 3B). A well-balanced soil microbiome is the foundation for healthy plants, healthy animals, and healthy food.

MICROBES ON THE FARM

Microbes do not just help plants—they play an important role in raising farm animals too. Animals' gut microbiomes help them digest food, stay healthy, and grow. The microbiomes of farm animals can be influenced by the plants they eat. When cows eat **silage**, which is plant material containing healthy microbes that help preserve it, those microbes can influence which microbes grow in the cow's gut and how well the cow digests its food. Farmers are finding ways to improve animal microbiomes—by adding helpful microbes to silage, for example (Figure 3B). When their microbiomes are in balance, cows, chickens, pigs, and other farm animals may produce more milk, meat, or eggs.

SILAGE

Preserved animal feed made from fermented grass or corn stored in airtight conditions.

Healthy animals help protect the food system. They are less likely to get sick from harmful microbes and may need fewer antibiotics. This is important because when animals get sick, they can spread harmful microbes and antibiotic-resistant microbes to other animals, to people, or into the environment. For example, bacteria in an animal's gut can end up in milk or meat, or can enter the soil and water. During storms, microbes from manure can wash into nearby rivers and oceans, where they can affect water quality and the health of other

ecosystems. In this way, farm animal microbiomes are connected to food safety, soil and water health, and environmental protection.

A balanced gut microbiome can actually benefit the environment. Through improving digestion, healthy microbes can reduce the amount of methane—a powerful greenhouse gas—that animals release [4].

GETTING TO YOU

By the time food reaches your plate, it has often taken quite a journey. It may have been washed, packed, shipped, stored, and sometimes cooked or frozen. Along the way, microbes travel with it. Some were there from the start—picked up from the soil, water, plants, or animals the food came from. Others join later, during handling, transportation or storage [5].

As we have already mentioned, not all these microbes are bad—some may even be helpful. Fresh fruits and vegetables often carry a natural mix of microbes from the farm that may support your gut health—especially when crops are grown in healthy soil and handled with care. Scientists call these communities edible microbiomes, and they are studying how they might benefit human health [6]. If harmful microbes are present—or if the good ones are outnumbered—they can spoil food or make people sick. Globally, 25–50% of the food produced spoils before it reaches people's plates, and microbes are a major reason why. Food producers are beginning to track the microbiomes of foods more closely to prevent food from going bad and to keep people healthy. The goal is not to remove all microbes, but to manage them—keeping the helpful ones while controlling the harmful ones [7].

MICROBES THAT *MAKE* FOOD...AND MAKE IT HEALTHIER

Some microbes are even part of the recipe for some well-known foods. Yogurt, cheese, bread, soy sauce, and sauerkraut are all made with the help of microbes, through a process called **fermentation**. Fermentation has been used for generations. In this process, special bacteria and fungi break down sugars and other ingredients to change the food in useful and desirable ways (Figure 3B). Fermentation can make food last longer, give it a different texture or flavor, or even improve its health benefits. Some microbes are added on purpose by food makers and others come from the raw ingredients themselves—like the cabbage used for kimchi or the milk used for cheese. That means the microbes that started in the soil or on a plant or animal might end up being a crucial part of the final product.

FERMENTATION

A desirable chemical process in vegetable and animal substances caused by bacteria and fungi, and used for thousands of years to stop food from spoiling and/or improve its flavor.

DIVERSE

A diverse microbiome means there are many different types of bacteria living together, each with unique shapes, jobs, and ways to survive, which helps keep the community healthy.

Fermented foods are not just tasty—they may also help support a healthy gut microbiome [8]. What you eat plays a big role in keeping your gut microbiome **diverse** and balanced. Fresh produce, fiber-rich foods, and fermented products can all support this balance. But ultra-processed foods—factory-made snacks and meals that are full of added sugars, fats, and artificial ingredients, and low in nutrients, fiber, and live microbes—can throw your gut microbiome out of balance, affecting digestion, immunity, and long-term health. Many steps in food production are important for safety and shelf life, but they also remove most naturally occurring microbes. Scientists are studying how traditional fermented foods or specific probiotics might help us keep our gut microbiomes healthy.

EVERYTHING IS CONNECTED

From the dirt under your feet to the food on your plate, microbes are part of every step of the food system. Some microbes help, while others harm. Healthy microbes help plants grow and support human and animal health, while harmful ones can damage crops, spread disease, or spoil food.

Each food microbiome is part of a larger web that links every part of the food system together (Figure 1). Microbes from the soil can move into plants. Plant microbes can be eaten by animals. Animal microbes can return to the soil through manure. And at the end of the chain, microbes from all these sources can affect the foods we eat—and the microbes in our own guts. That means a change in one part of the system—like losing microbial diversity in the soil or overusing antibiotics on a farm—can affect everything that follows, including human and environmental health. These connections can be invisible, but they are powerful.

Scientists, farmers, and food producers are studying these links to find better ways to protect and guide microbes across the food system. The goal is not to get rid of microbes, but to support the right ones in the right places. By learning how microbes connect agricultural soil, farm animals, food, people, and the environment, we can make smarter decisions—for our health, for the planet, and for the future of food.

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YOUNG REVIEWERS

ARAM, AGE: 11
My name is Aram, and I am 11 years old. I enjoy playing the piano and coding on Scratch. My favorite subject is Math, and I speak three languages. I have won my school's Spelling Bee competition three years in a row! When I grow up, I would love to be an engineer. I am always curious and excited to explore new ideas and be creative.

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Paula Fernández Gómez is an assistant professor at Universidad de León in Spain. Her research started in the world of food safety, focusing on innovative technologies to prevent microbial contamination in food production plants. Over time, her interests have shifted toward the development of functional fermented plant-based foods, using the knowledge about their communities of microorganisms to obtain healthy and appetizing foods. In her free time, she likes to hike, paint, and enjoy time with family and friends. *pafeg@unileon.es

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