Termites Digest Wood Thanks to Microbes

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Film Guide
Educator Materials

OVERVIEW

Termites Digest Wood Thanks to Microbes is one of 12 videos in the HHMI series "I Contain Multitudes," which explores the fascinating powers of the *microbiome*: the world of bacteria, fungi, and other microbes that live on and within larger life forms, including ourselves.

The termite gut teems with microbes that are essential for the digestion of cellulose. Without these microbial symbionts, termites would be unable to digest wood. This is an example of mutualism, in which both the termites and the microbes benefit. In *Termites Digest Wood Thanks to Microbes*, award-winning author Ed Yong interviews Princeton scientist Xinning Zhang, who makes viewers aware of the interconnectedness of individual organisms and the multitudes of symbiotic microbes living in their digestive systems. She answers questions about why microbes are necessary for termite digestion of wood and how the microbes are passed from adult termites to offspring.

KEY CONCEPTS

A. Symbiosis is a close, long-term interaction between organisms belonging to two different species. One, both, or neither species may benefit from the relationship. When both species benefit, the relationship is called mutualism.
B. Microbes can play important roles in maintaining the health of larger host organisms.
C. Digestion consists of both the mechanical and chemical breakdown of food.
D. Microbes can assist other organisms in the enzymatic, or chemical, phase of digestion.

CURRICULUM CONNECTIONS

Standards	Curriculum Connections
NGSS (2013)	LS1.C, LS2.A, LS2.B
AP Biology (2015)	2.D.1, 4.B.2, 4.B.3
AP Environmental Science (2013)	II.A
IB Biology (2016)	4.1
IB Environmental Systems and Societies (2017)	2.1
Vision and Change (2009)	CC2

PRIOR KNOWLEDGE

Students should

- have a basic understanding of the process of digestion;
- be familiar with the role of enzymes in the digestive process;
- know that carbohydrates are important nutrients in the diet of humans and other organisms;
- know that microbes can be beneficial, harmful, or neutral in their effects on other organisms;
- know the difference between a fact and an inference and the role of scientific investigation in providing evidence to support an observation being a fact.

Note: The video approaches these topics at a basic level, so it could serve as an introduction to these topics as well as a launching point for deeper learning.

PAUSE POINTS

The film may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content Description	Review Questions
1	0:00	1:25	• During the process of digestion, food is first ingested. • Big pieces of food are broken down into smaller ones. • Nutrients and energy-bearing molecules are absorbed by the body. • Animals require the assistance of microbes to digest plant material.	• Why do animals require the assistance of microbes when digesting plant material?
2	1:26	3:45	• Animal-gut microbe partnerships have existed since animals first evolved and have shaped the evolution of the animal digestive system. • Humans rely on gut microbes to help digest our food. • Microbes were the first life forms on Earth and play an important role in the health of the environment and the health of other organisms. • Protists are one type of microbe observed in the termite gut.	• Why must termites break down wood into small particles? • Describe some ways in which microbes affect the health of the environment. • What do the protists in the termite gut break cellulose down into?
3	3:46	7:10	• Termites evolved from an omnivorous cockroach species. • The social behavior of members of an ancestral cockroach-like species allowed them to take advantage of abundant wood resources. • Gut microbes are passed from adult termites to juveniles through social behavior.	• What group behavior played a role in the evolution of termites from a cockroach-like species?

BACKGROUND

Termites are fascinating insects that play a major role in nutrient recycling in terrestrial ecosystems, are key links in many vertebrate food chains, and are a bane to many homeowners. There are approximately 3,000 species of termites and most are relatively small, ranging in size from 4 to 15 mm in length. Due to their size and general appearance, they are sometimes referred to as “white ants.” However, morphological and genetic analyses indicate that they are not ants but instead are closely related to wood-eating cockroaches and evolved from within a lineage of cockroaches about 150 million years ago. Termites and cockroaches both belong to the order Blattodea. Termites are found on every continent except Antarctica. Termite species can be grouped by the ecological regions in which they live; dampwood (found in coniferous forests), drywood (found in hardwood forests), subterranean (found in widely diverse areas), and arboreal/mound builders. The 185 or fewer species of termites that are pests for humans have been estimated to cause $1 billion to $2 billion in damage each year in the United States.

Termites play a major role in nutrient cycling because many species harbor microbes that can break down the major carbohydrate in wood, a molecule called cellulose, which is resistant to decay and cannot be digested by most insects or animals. Microbes in the hindgut of a termite break down cellulose into more easily digested sugars and short-chain fatty acids. These fatty acids are taken into the cells of the termite and used as nourishment in the same way human cells take in nutrients processed by our digestive system.

Like ants and bees (order Hymenoptera), termites have independently evolved a complex social structure and a division of labor called eusociality, also found in bees and ants. Eusociality evolved in termites about 50 million

years earlier than it did in hymenopterans. A termite colony, which can range in size from a few hundred to several million individuals, contains three castes: reproductives, workers, and soldiers. Reproductives include fertile males (kings) and one or more fertile females (queens). Workers are sterile and participate in nest building, foraging and feeding, and caring for immature termites. Soldiers are also sterile and defend the colony. Together, the termites of a colony function in ways analogous to a single multicellular organism.

Not all termites consume cellulose, but those that do have a specialized midgut teeming with microbes (primarily protists, bacteria, and archaea) that break down the cellulose. The relationship between the termites and the microbes is a mutualism, because both species benefit from the relationship. The termites masticate the wood to mechanically break it down, and the microbes chemically digest the wood into smaller molecules that the termites are able to absorb and utilize. The termite gut provides microbes with a stable environment and food. A single termite species contains several hundred species of gut microbes that have co-evolved with that species. Some species of these protists themselves host an intracellular bacterial species that makes some required digestive enzymes.

Most termites are blind, so they must communicate through mechanical or chemical means. The most common form of communication is through antenna touching. Many termites also communicate by releasing chemicals known as pheromones that affect the physiology or behavior of other members of the same species. Some termite pheromones are laid down in a track to help other termites find a food source. A number of pheromones are known, including contact pheromones, which are transmitted when workers are engaged in trophallaxis. Genome comparisons of termites and cockroaches demonstrate that there have been substantial adaptive changes in genes underlying the production and perception of pheromones as termites diversified over time.

DISCUSSION POINTS

- In the short film *Termites Digest Wood Thanks to Microbes*, we learn that the digestion of wood requires the assistance of a variety of gut microbes. These microbes are a part of the gut microbiome. Discuss what would happen to termites if their gut microbiome was damaged or destroyed.
- Help students understand that like termites, humans and other organisms possess communities of microbes living in their digestive systems. Ask students to think about why the human gut microbiome might be important.
- Connect the content of this video to students' understanding of common ancestry by asking how the speciation of termite species likely affects the speciation of the microbial species in their guts. Because the lives of the microbes are so intimately tied to the lives of the termites, the species co-evolve so that when termite species split and form new species, so do the microbes.
- Help students understand that the human gut microbiome is composed of communities of symbiotic bacteria, fungi, protozoa, and viruses. Some of the relationships they form with us are mutualistic, communalistic, and parasitic.
- Help students understand that antibiotics can damage the human gut microbiome and change the community composition of the microbiome. Discuss with them how this might be similar to damaging the microbiome of termites. Have students discuss and share ideas for restoring their gut microbiome should it be disrupted by taking antibiotics. Ask students how eating fermented foods that contain live microbes, taking a probiotic supplement, or eating probiotic foods such as yogurt, kombucha, and fermented vegetables might promote a healthy microbiome.
- Discuss how proctodeal trophallaxis (butt licking) in termites might be similar to the medical procedure known as fecal microbiota transplant.

- Students may be interested to learn about the process of rumen transfaunation in dairy cows, which involves transferring microbes from a healthy animal to a sick one. Note that microbiota used to be called microfauna, which explains the origin of the term transfaunation. In this process, rumen fluid from a healthy animal is transferred to a sick recipient. This procedure is used to treat indigestion and enhance milk production. Discuss how this process is similar to and different from proctodeal trophallaxis in termites and the ingestion of probiotics or fecal transplants in humans. Stress how all of these applications emphasize the importance of a healthy gut microbiome.

STUDENT HANDOUT

The student handout is available as a separate file. It is designed as a learning assessment that probes students' understanding of the key concepts addressed in the film and can be used to assess students' prior knowledge before watching the film or to guide students as they watch the film. We encourage you to choose the use that best fits your learning objectives and your students' needs. Moreover, because the vocabulary and concepts are complex, we encourage you to modify the handout as needed (e.g., reducing the number of questions, explaining complicated vocabulary for English learner students).

ANSWER KEY

1. [Key Concept C] What serves as a preferred food source for the termites featured in this film?
   a. leaves
   b. protists
   c. simple sugars
   d. *wood*

2. [Key Concepts C and D] Explain why termites are able to digest wood when humans cannot.
   Humans do not synthesize enzymes needed to digest the cellulose found in wood. However, termites possess microbes that synthesize the enzymes that allow wood to be chemically digested.

3. [Key Concepts A, B, and D] Why is it important for microbes found in the guts of adult termites to be passed to juvenile termites?
   The termites need the microbes because they make cellulose-digesting enzymes. Without the microbes, the young termites would not be able to obtain nutrients from the wood they ingest.

4. [Key Concept C] Large molecules present in the food of termites are broken down into smaller molecules. Why is this important?
   a. Only small molecules can be absorbed by the microbes found in the guts of termites.
   b. *Large molecules of cellulose cannot be absorbed into the cells of the termites.*
   c. Enzymes present in the gut microbes cannot act on large molecules.
   d. Gut microbes synthesize nutrients needed by the termites from the small molecules.

5. [Key Concepts A and B] Explain how partnerships between animals and gut microbes have shaped the evolution of the digestive systems.
   In the case of termites, their guts have evolved in a way that provides the necessary abiotic and biotic factors for specific microbes to grow and reproduce. These microbes digest the food the termites ingest. The same has occurred in the evolution of the digestive systems of other animals. The film discusses the importance of the human gut microbiome in helping us digest many plants. Another example not included in the film but that may be known to students is the rumens found in cattle and sheep.

6. [Key Concept A] In a mutualistic relationship, both species benefit from their interactions with each other. Which of the following is a benefit that the microbes receive from living inside termites?
   a. The microbes get access to simple sugars from the termites.
   b. *The microbes are provided easy access to wood, a source of food.*
   c. The microbes make wood from the food consumed by the termite.
   d. Termites make energy and the microbes are able to use it.

7. a) [Key Concepts A, B, and C] Explain how a termite benefits from the microbes inhabiting its gut. Support your answer with information you learned in the film.
   The microbes digest the wood into molecules that provide the termite with nutrients and energy.

   b) [Key Concept A] Symbionts are organisms living in a symbiotic relationship. Termites and their gut microbes are examples of symbionts. State why the microbes inhabiting the termite gut are classified as *endo*symbionts.
   The symbiotic microbes live inside of the termite. This makes them endosymbionts.

8. [Key Concepts A – D] Facts are statements based on data; there is evidence to support them. Inferences are assumptions based on what you observe; they are logical conclusions and can be correct or incorrect.

   Based on what you have learned from the film, indicate which of the following statements are facts and which are inferences by writing an "F" or an "I" in the box next to the statement. Provide evidence to support your decision in the last column.

	Statement	Fact (F) or Inference (I)	Evidence
a.	Termites chew up and ingest wood.	*F*	*This fact was directly observed in the film.*
b.	The microbes inhabiting the guts of termites are endosymbionts.	*F*	*Endosymbionts are defined as organisms living in a state of symbiosis and one of the symbionts lives inside the other. The relationship between the termites and the gut microbes is symbiotic because the microbes live in a close physical association with the termites and in this situation, both benefit.*
c.	Termites evolved from cockroaches.	*F*	*This fact was stated in the film.*
d.	If the termite gut microbes are destroyed, termites will die.	*I*	*Because termites rely on microbes to chemically digest cellulose, without the gut microbes, termites would probably not be able to obtain nutrients and energy from the food they ingest. Evidence to support this inference could be obtained if termites were experimentally altered to not have gut microbes.*
e.	Humans possess gut microbes that aid in the digestion of plant material.	*F*	*This fact was mentioned in the film.*
f.	Trophallaxis is an instinctive behavior that termites engage in without having to learn it.	*I*	*The film provides information about trophallaxis but does not state whether it is instinctive or a learned behavior. An experiment that could test whether this inference is true would be to provide young termites with access to feces but no living adults to teach them to ingest feces.*

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