Chocolate: Our Favorite Treat

Daddy: Cynthia says chocolate has mold in it! Is this true?

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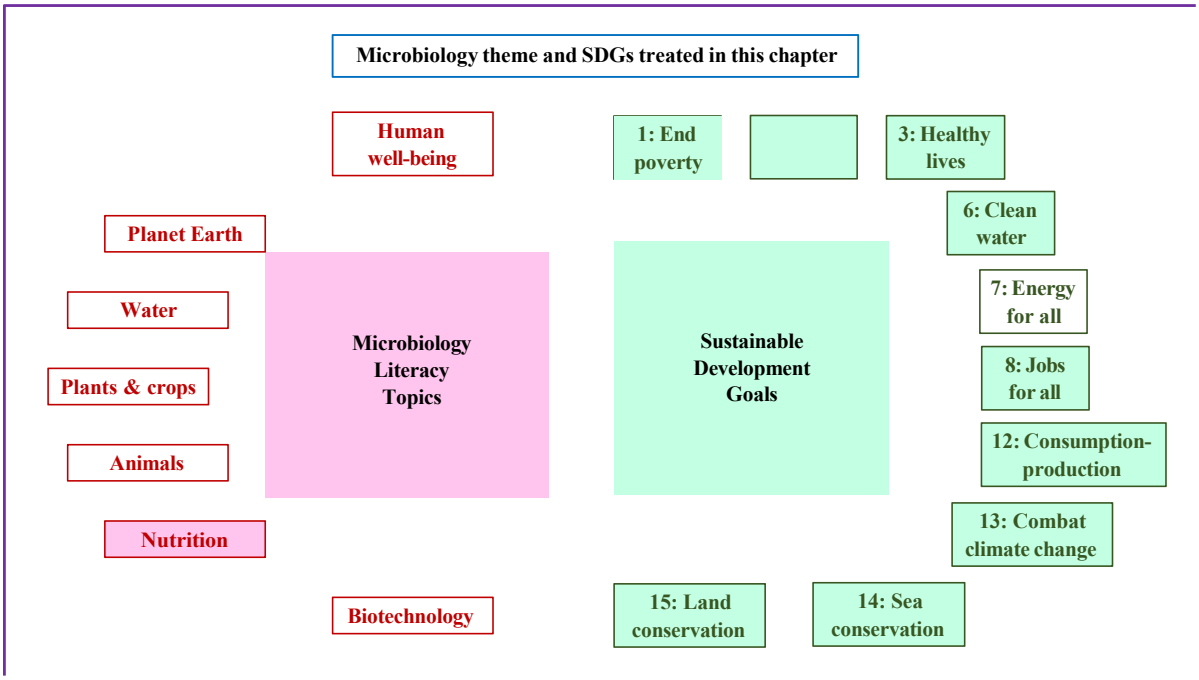
Chocolate

Storyline

Chocolate is one of the world's most widely enjoyed treats. It is associated with romance, rewards, and comfort food (relaxation). Recently, it has also achieved an association with health foods because the plant that produces cacao pods, *Theobroma cacao*, is high in healthful antioxidants. However, chocolate's reputation as a health food is undeserved because most of the antioxidants are degraded during processing. Most people don't realize that chocolate is a food produced by microbial fermentation, like yogurt and kombucha. The extensive fermentation process develops its flavor: *without fermentation, it does not taste like chocolate!* The fermentation microbiome includes yeast, bacteria, and filamentous fungi (mold). Knowledgeable farmers guide it through this difficult process despite many challenges. *Theobroma cacao* is a difficult plant to grow. It is beset by pests and environmental challenges. The social cost and environmental footprint of raising this crop are high. In the future, when we enjoy chocolate, we should appreciate all the care and work (by both humans and microbes) that went in to bringing it to our supermarket shelves. Focus on Sustainable Development Goals will help us understand and appreciate chocolate properly.

The Microbiology and Societal Context

The microbiology: Cacao endophytes and mycorrhizae, tree and soil infection and parasitology, and cacao agronomy generally. Cacao fermentation microbiome; differences between yeast, mold, and bacteria. Concept of microbial succession. *Sustainability issues:* Agroforestry and sustainable growing practices, soil management, pest management, economics and labor issues.



A child-centric microbiology education framework

Chocolate and Cacao: the Microbiology

1. ***Cacao trees (Theobroma cacao) grow with the help of endophytes and mycorrhizae.***

When you think of a tree, you probably think of a single organism standing tall and growing individually. However, the cacao tree (and all other trees!) are inhabited by symbiotic organisms; they grow with the help of microbes on their roots and leaves. The tree that gives us chocolate is known as *Theobroma cacao*. It produces brightly colored football-shaped fruits whose seeds will later be turned into chocolate.

Photos by Jeana Cadby

This tree is inhabited by fungal symbiotes on its leaves, known as endophytes, and on its roots, known as mycorrhizae. The root symbiotes consume some of the sugars that the tree produces through photosynthesis. In turn, they make available nutrients (like phosphorus) from the soil that the tree badly needs but cannot extract on its own. The leaf (foliar) endophytes probably play a critical role in pest protection. In fact, many of them are closely related species of those parasites that plague cacao crops. Probably, foliar endophytes confer some degree of resistance to common fungal pests.

2. ***The cacao tree is plagued by fungal parasites and viral infections.*** Just like people, plants can get infections! Some of the most common infections of the cacao tree are fungal: witches' broom (*Moniliophthora perniciosa*), frosty pod rot (*Moniliophthora roreri*), black pod rot (*Phytophthora* spp), and vascular streak dieback (*Ceratobasidium theobromae*). Other common infections are viral, like cacao swollen shoot virus.

Cacao Black Pod Rot (*Phytophthora palmivora*). Photo by the International Institute of Tropical Agriculture

Witches Broom Fungus (*Moniliophthora perniciosa*). Photo by USDA; ARS.

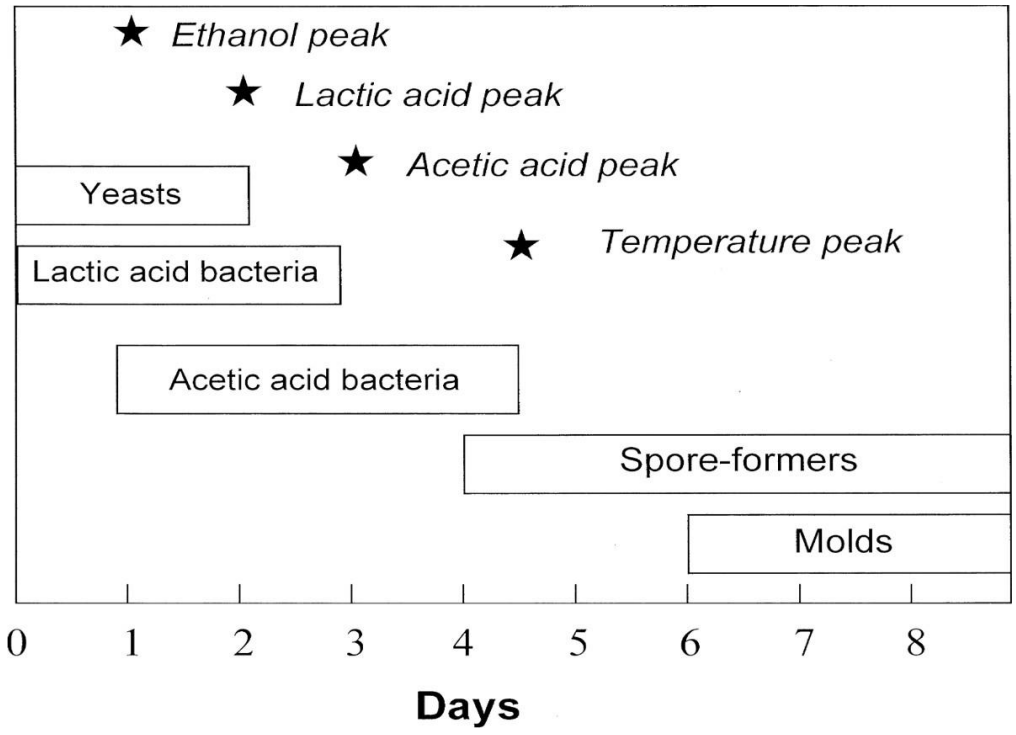
3. ***Management of the soil microbiome helps reduce the load of pests and improved crop yield.*** Soil with a rich load of microbial biomass has been shown to be more resilient and to store more nutrients (Mortimer, Saj, & David, 2018). Soil and root microbes improve nutrient cycling by breaking down biomass (like leaf litter) to make its components available as nutrients, and they also improve nutrient uptake. They are also competitive inhibitors of potential pests and pathogens. All of this leads to healthier plants, increased yield, and reduced loss to pests.

4. ***Chocolate is a fermented food; fermentation gives chocolate its flavor. Without fermentation, it would not taste like chocolate!*** The fermentation step includes yeast, bacteria, and mold. First, the seeds of the cacao tree, and the pulp that surrounds them, are poured into a wooden box and covered with banana leaves. Yeast, bacteria, and mold from the box, leaves, and the hands of the workers mix with the seeds and pulp. A very complex process begins. First, yeast convert sugars in the pulp into alcohol. Simultaneously, molds and yeasts work to break down the pulp so it drains away. Then, acetic acid bacteria turn that alcohol into acetic acid. This process produces heat (is exothermic), and the fermenting mass can become as hot as 50°C! The heat kills the germinating seed. The acid soaks into the beans and causes many biochemical changes, such as degradation of

proteins and polyphenols (Schwan & Wheals, 2004). Eventually, most of this acid evaporates, and the beans begin to cool off. Then the beans finally dry out and all the microbes die off. Only now are the beans ready to be processed into chocolate—but it will still take many more steps before they are ready to be eaten!

An early-stage. fermentation. Photo by Irene Scott of AusAID via Wikimedia Commons.

A late-stage fermentation. Photo by Jeana Cadby.



The progress of a typical cacao fermentation; major organism categories and important biochemical peaks. Adapted from Schwan & Wheals (2004).

Chocolate and Cacao: the Social Issues

5. ***Chocolate production is extremely time- and labor-intensive.*** Many people participate in the process of cacao and chocolate processing. The long process begins with the farmers, who grow and care

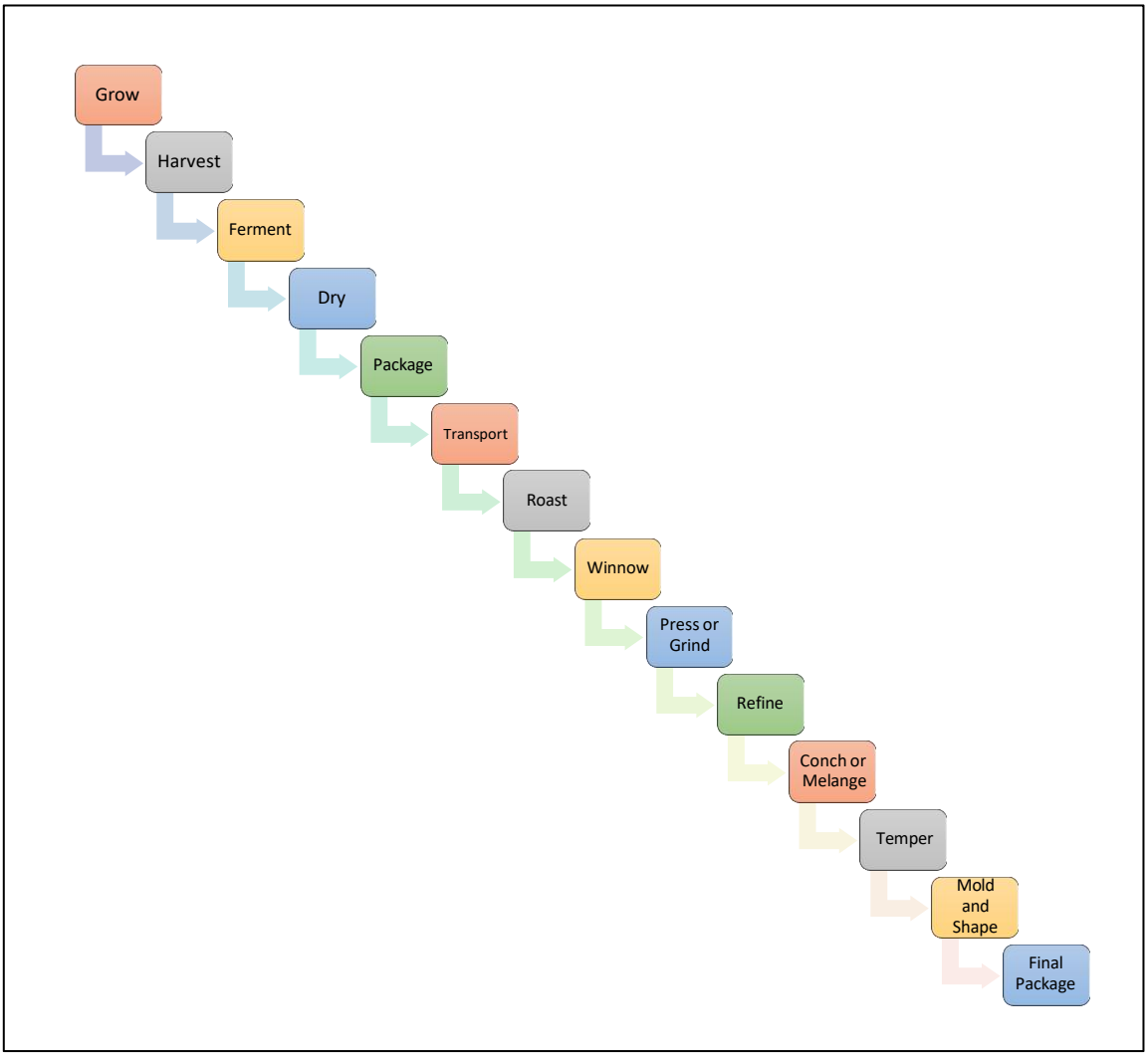
for the cacao trees, which are a very difficult and labor-intensive crop. Next, workers harvest the cacao pods, separate the diseased ones, and scoop out the seeds.

Cacao pods after harvest. Some diseased pods visible.
Photo by ICCFO via Wikimedia commons.

Then they must be transported to the fermentation site. Next, fermentation takes place. Fermentation is described above. It takes 3 to 12 days, and it must be closely managed by skilled workers. Afterwards, the beans must be transported to a trying facility where they dry for around 10 days. This process is very weather-dependent and requires close monitoring. To avoid mold growth, the beans are constantly moved and turned for all ten days, as shown in the photo below. Next, the beans are cleaned, then sorted, then packed for transport in large sacks. The sacks are shipped to a chocolate-maker in a different part of the world.

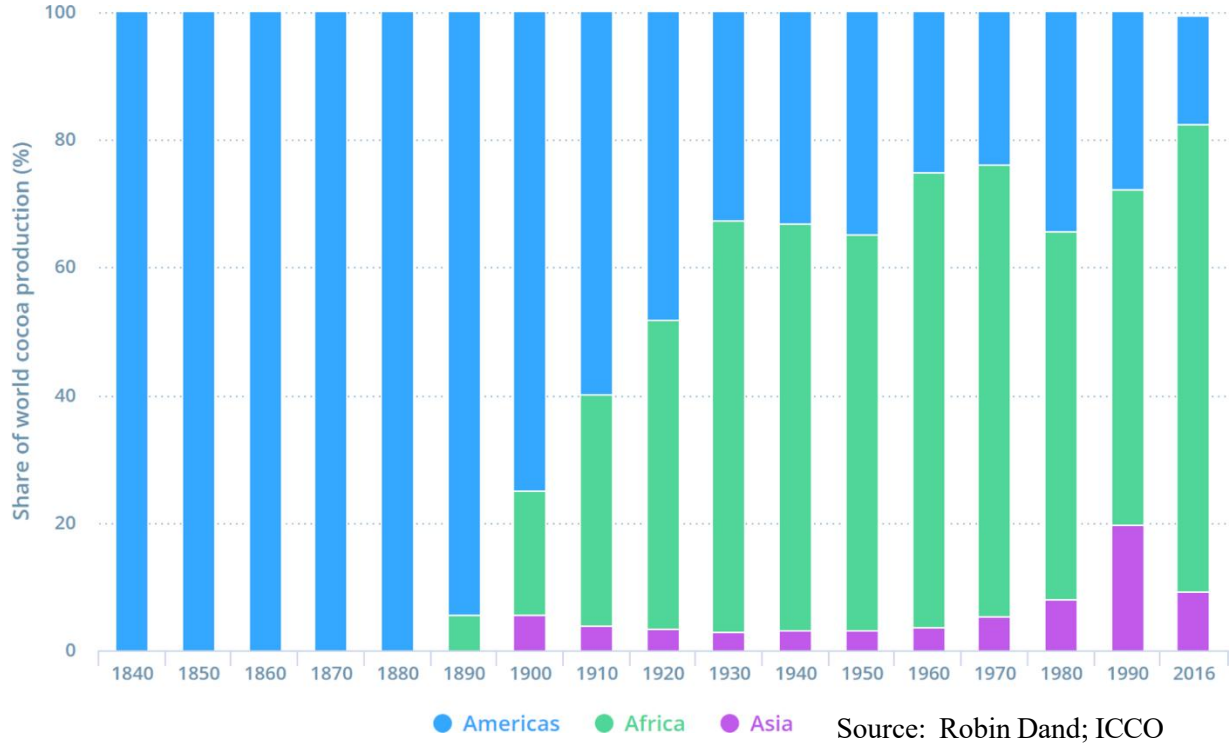
The chocolate-maker will roast and peel (winnow) the beans, then grind them or press them (depending on the type of chocolate being made). Next, he or she will refine (crush) them with sugar and sometimes milk powder for many hours or sometimes several days in a process called conching or melanging (for smaller volumes—shown below). Still the chocolate is not ready; it must be tempered (heated and cooled to precise temperatures) to give it the right texture. All of this requires many weeks of labor and specialized equipment.

Photo via Pixabay Creative Commons license



Steps to chocolate-making from tree to bar

6. ***As the environment changes, cacao farmers must adapt in order to feed their families.*** In many parts of the world where cacao is grown, the climate is changing dramatically. Some farms are drying out, forcing farmers to seek new land. Other farms are exposed to pests and pathogens that they have never dealt with before. These difficulties force farmers to innovate and occasionally to abandon their farms. However, in some areas, it is becoming possible to grow cacao where it has never been possible before! Cacao of excellent quality is now grown in China, India, and Vietnam—all places where the climate previously did not permit the growth of this crop. See the chart below, which shows global cacao production shifting towards Asia and away from Africa and the Americas.



Source: Robin Dand; ICCO

7. ***Chocolate-making produces waste streams.*** Chocolate is made from the seeds of the cacao fruit. The hard outer layer, called the exocarp or shell, comprises most of the fruit by weight. It is thrown away before fermentation, and not used for any part of the chocolate-making. This results in huge amounts of waste which must be disposed of so that its decomposition does not attract unwanted fungal pathogens. Some farms attempt to compost the exocarp waste, while others use it as animal feed. Still other farms have found that it can be used to make paper and textiles. Regardless, the huge volume of waste that cacao farms must process has been a problematic aspect of this crop.

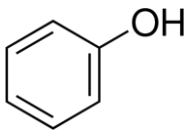
Chocolate-makers also experience waste. Once cacao beans are roasted, they undergo a process called "cracking and winnowing" in which the papery outer husk of the beans is separated away from the meaty inner par, known as nibs. Nibs are used to make chocolate, while husk is a waste product. Some chocolate-makers sell their husk to other industries. For example, it is popular in the brewing industry, because it is highly aromatic and makes chocolate-scented beer! It can also be used for vermiculture and composting.

Photo by Caitlin Clark

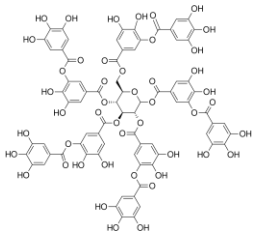
8. ***Chocolate is not a health food or "superfood", despite its reputation.*** Many people believe that chocolate is rich in healthful compounds called polyphenols; often, they have been told this by a doctor or nutritionist. However, science does not support this claim.

What are polyphenols?

Polyphenols are organic compounds composed of phenol units. Phenol units are rings of carbons with an OH group attached. One phenol group looks like this:



A polyphenol, composed of many phenol groups, looks like this:



Polyphenols have been shown to reduce bodily markers of oxidative stress and protect against diabetes. They may also help mobilize free fatty acids, the major fat fuel in the body, after exertion. They chelate metals and trace elements and scavenge free radicals, although the mechanisms of this have not been fully studied or described. Some studies tout their effectiveness against cardiovascular disease.

While polyphenols generally have a positive association with health (except at extremely high doses), their contribution to chocolate sensory properties tends to be negative. High levels of any type of polyphenol can result in high perceived astringency. For this reason, certain processing steps are carried out in order to reduce polyphenol content during chocolate-making. Raw cacao beans are extremely high in polyphenols; however, the processing of cacao into chocolate includes many steps to drastically reduce these antioxidant compounds, causing a decrease in their concentration, in some cases

to 0%. In addition, because cacao genetics, harvesting, and fermentation practices are different in every geographic locale, the amount of antioxidant polyphenol compounds in chocolate is hugely variable and sometimes as low as 0%. It is very difficult to guarantee the polyphenol content of a given piece of chocolate, despite its common recommendation by nutritionists as a polyphenol-rich "superfood". A recent study indicated that an intake of more than 650 milligrams of polyphenols per day was associated with a 30% reduction in mortality among adults On the other hand, a reasonable guess at the polyphenol content of a typical dark chocolate bar is 1g/100g, or 0.5 g per 50 g bar. Even if all these polyphenols are bioavailable (which is unlikely), this means that eating an entire chocolate bar per day would only contribute a portion of the day's required polyphenol content, at the cost of excessive daily sugar and fat consumption. For this reason, fruits and vegetables are a much better recommendation for those who wish to consume a polyphenol-rich daily diet. For example, plums are estimated to contain 4g/100g, while strawberries probably tally around 2g polyphenols per 100 g of fruit. Both of these are richer in polyphenols than dark chocolate and they lack the sugar and fat of a chocolate bar.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of cacao and chocolate relates to several SDGs (*microbial aspects in italics*), including

- **Goal 1: End poverty in all its forms everywhere** *(increase rights to economic resources such as crop seeds and pesticides where necessary, increase the resilience of the poor to extreme climate events).* Cacao is a crop subject to extreme economic peaks and valleys, forcing farmers to respond in similarly extreme manner. They may expand their field using a slash-and-burn technique, or they may abandon productive trees in favor of a higher-grossing crop. By understanding the incredibly labor-intensive process required to make cacao beans needed for chocolate, consumers may be willing to pay a higher price for the end product, stabilizing the market and allowing farmers to engage in more sustainable and consistent farming practices that provide more resilience to climactic and economic shifts.
- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture** (*end hunger and malnutrition, increase agricultural productivity)*. While cacao is a resource-intensive crop, it is important to understand that in many cases it is grown alongside other crops (often food crops). This strategy is known as "intercropping" or "agroforestry" and its popularity is increasing due to its demonstrated sustainability and excellent results. In this way, the same density of land can be used to grow an economically important crop such as cacao alongside food crops like mango, coconut, or banana; many farms grow multiple food crops and even cash crops such as timber wood or vanilla orchid alongside their cacao. This improves not only the food security of the farmer but the overall sustainability of the land; agroforestry practiced in this manner shows a more diverse soil microbiome and an improved soil composition overall, more efficient water uptake and nutrient cycling, and more power over shade management which can be used for pest control, leading to reduced use of pesticides.
- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (*improve health, reduce preventable disease and premature deaths).* Many cacao farms are family farms, worked by family members of all ages. It is important to ensure all laborers a safe and healthy work environment. Cacao farming is often a community activity, with work such as fermentation and drying shared by multiple community members at a cooperative or other central location. Sometimes resources and profits are pooled for the benefit of the community. Of course, chocolate (the final product!) is a treat enjoyed by all ages! Although it probably does not promote physical well-being as much as some nutritionists hope (see above section regarding polyphenols), it certainly enhances mental and psychological well-being and has even been shown to improve mental acuity.
- **Goal 6. Ensure availability and sustainable management of water and sanitation for all** (*assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and*

sanitation management). The organic waste from cacao pods may pollute nearby water sources, as can runoff from pesticides if they are used. Sustainable farming practices such as composting, intercropping, and shade management (which reduce the reliance on pesticides) can improve water sanitation.

- **Goal 8. Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all** (p*romote economic growth, productivity and innovation, enterprise and employment creation)*. The chocolate industry suffers under an economic structure that promotes both child and adult slavery. Despite this being well-documented, the industry has little incentive to restructure. Only consumers who are willing to demand that their chocolate is sourced from a supply chain with a record of fair and inclusive employment can solve this problem. This will certainly raise the price of the chocolate; recent studies show that younger consumers are more willing to pay more for chocolate if it includes some indicator of trust in sourcing. These young consumers are the only hope for the thousands of modern-day slaves who still labor, unpaid and unfree, on cacao plantations. However, most cacao plantations are not operated by slaves; there an increasing number of excellent quality chocolate options available with a supply chain from trustworthy sources.
- **Goal 12. Ensure sustainable consumption and production patterns** *(achieve sustainable production and use⁄consumption practices, reduce waste production⁄pollutant release into the environment, attain zero waste lifecycles, inform people about sustainable development practices)*. Cacao pod waste is greater, in terms of mass, than the total mass of chocolate produced from the cacao seeds. Disposing of this waste properly and in a manner not harmful to the environment is becoming one of the central issues of this industry as it continues to grow.
- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global warming)*. The unsustainable economic structure of the cacao industry has led to a cycle of slash-and-burn agriculture that has eliminated up to 90% of protected forest land in some parts of Western Africa, leaving the land bare and exposing it to intense solar radiation and erosion. These practices are also increasing fallow periods and threatening deforestation in Latin America. Land that has suffered in this way is less available for agriculture and is unable to host a great variety of species on either the micro or macro level.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development (***reduce pollution of marine systems by toxic chemicals⁄agricultural nutrients⁄wastes like plastics, develop mitigation measures for acidification, enhance sustainable use of oceans and their resources)*. N, P, and pesticide use associated with cacao production, where they occur near coastal waters, may run into marine systems. Proper shade and soil management and sustainable practices like agroforestry and inter-cropping can reduce use of N, P, and pesticides.
- **Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss** *(promote sustainable management of all forests, halt deforestation).* The agroforestry strategy described above is not only important for farmer resilience. It is also very important for forest management. Most cacao farming is performed in forests. An intercropping strategy increases the resilience of the forest by improving soil quality and increasing the biodiversity of the microbiome and of the large species that roam the land and air. It reduces the resource load as symbiotic species aid each other in nutrient cycling. It decreases water use. It improves the resilience to pathogens. Agroforestry (intercropping) is not only a farming tool; it is a form of forest management.

Potential Implications for Decisions

A child-centric microbiology education framework

1. *Individual*

a. Weighing up the various microbial and non-microbial factors and aligning them with personal convictions (do the personal positive health benefits of eating chocolate outweigh the social and environmental considerations?).

b. Now that you know how chocolate is made, and all the many microbes that are involved, does it make you more excited or less excited to eat it?

c. Now that you have learned more about chocolate, do you think it should be an "everyday" food like coffee or bread, or a special treat food like lobster or Champagne? Why?

2. *Community policies*

a. Labor markets affected—should children be allowed to work, even on a family farm? What does "slave" mean in the modern world? What would it feel like to be a be a child slave on a cacao farm? What steps should the global community take to prevent this from happening? Why do you think farmers buy slaves for their farms—what could cause them to be so desperate?

b. Economic markets affected—In order to increase prices for farmers, prices would have to increase for consumers. Is that acceptable? Are there any other ways the economic system could be restructured? How could concepts like "direct trade" be employed to everyone's benefit? Why aren't these systems used more widely now?

c. Nonmicrobial parameters: fairness of labor policies, responsibility of consumers, Fair Trade, direct trade.

3. *National policies relating to cacao and chocolate*

a. Healthcare policies in terms of nutrition recommendations
b. Import limitations
c. Consumer education
d. Non-microbial parameters: health care policies, trade policy and import/export

Pupil Participation

1. *Class discussion of the issues associated with cacao and chocolate*

2. *Pupil stakeholder awareness*

a. Chocolate production has positive and negative consequences for the SDGs. Which of these are most important to you personally/as a class?

b. Can you think of anything that might be done to reduce the negative consequences, especially in the food supply chain?

c. Can you think of anything you might personally do to reduce the environmental footprint chocolate consumption?

3. *Exercises*

a. Most cacao farms compost their cacao pod waste, but often there is simply too much volume even for composting. Can you think of anything else they could do with this large volume of organic waste?

b. Why do you think agroforestry/intercropping (growing many crops together on the same land) is more sustainable than monocropping (growing a single crop on a plot of land)? Can you think of any other long-term negative consequences to monocropping? How could you convince a farmer to try an intercropping strategy?

c. Look at Box 1, which shows the steps to chocolate-making from tree to chocolate bar. At which steps are there opportunities to incorporate changes that promote the SDG? Why did you

identify those steps? Who would be responsible for making those changes—the farmer or the chocolate-maker?

The Evidence Base, Further Reading and Teaching Aids

For younger kids

1. https://www.youtube.com/watch?v=zJdeQABAc_w (Where Does Chocolate Come From? video)

For middle kids (possibly adaptable to older or younger?)

2. https://www.youtube.com/watch?v=iC-EnTZrddk (Chocolate Factory Field Trip video)
3. http://www.teachingwithtlc.com/2015/02/fun-learning-activities-with-chocolate.html (learning activities with chocolate--several suggestions for activities and lesson plans)
4. https://blog.pitsco.com/blog/chocolate-covered-learning (STEM activities with chocolate)

For older kids

5. https://www.youtube.com/watch?v=P_JuQCiKWUc (How It's Made video)
6. https://www.youtube.com/watch?v=-PIgY4Wr23c (History of Chocolate video)

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Glossary

Agroforestry: a style of farming and forest management in which forest trees are deliberately used on the same land as an agricultural crop. This provides benefits in terms of shade management, nutrient cycling, and species richness, such that the entire system, including the agricultural crop, is healthier and more sustainable long-term.

Antioxidant: a molecule that slows or prevents cell damage from free radical particles.

Conch: an agitating scraper, often in paddle form, that mixes together cocoa fats, sugar, and cocoa solids, evenly distributing the fats over the solid particles. This process is usually used in large-scale chocolate-making, and it follows a refining (particle size reduction) step, which occurs separately.

Endophyte: a fungus that lives on or in another plant; the word implies symbiotic relationship.

Exothermic: leading to the release of heat.

Fermentation: a process in which microbes act upon a substrate (usually food) to change it in a way that improves its sensory or nutritional qualities, or to preserve it.

Intercropping: a farming practice that involves growing two or more crops on the same space of land; usually these crops are in some way symbiotic or co-beneficial, and often the practice involves more than two crops, forming a complex farming system.

Melanger: a large stone grinder in which a granite wheel grinds cacao nibs and sugar until their particle size has been sufficiently reduced and the fats have been evenly distributed over all the solid particles. This process usually occurs in small-scale chocolate making. Unlike conching, in melanging the refining (particle size reduction) and mixing both occur during the same step.

Mycorrhizae: a fungus growing on the roots of the tree that exists in a symbiotic relationship with that tree.

Polyphenol: a type of antioxidant compound that also acts as a pigment, giving color to foods (usually purple, red, and blue colors).

Slash-and-burn: a farming practice in which forestland is burned to clear the existing vegetation so that new seeds may be sown. This practice contributes significantly to deforestation**.**

Symbiote: an organism living in a mutually beneficial relationship with another organism.

Vermiculture: the process of raising worms for the purpose introducing them to an organic compost mixture.

Winnowing: the process of separating the cacao nib from the cacao husk.