Fruit flies and their microbes

Miss: Mum was so upset this morning because most of the apples she bought for my lunchbox had a circular area of rotting. What do you think caused this?

Image by Sanjay Acharya

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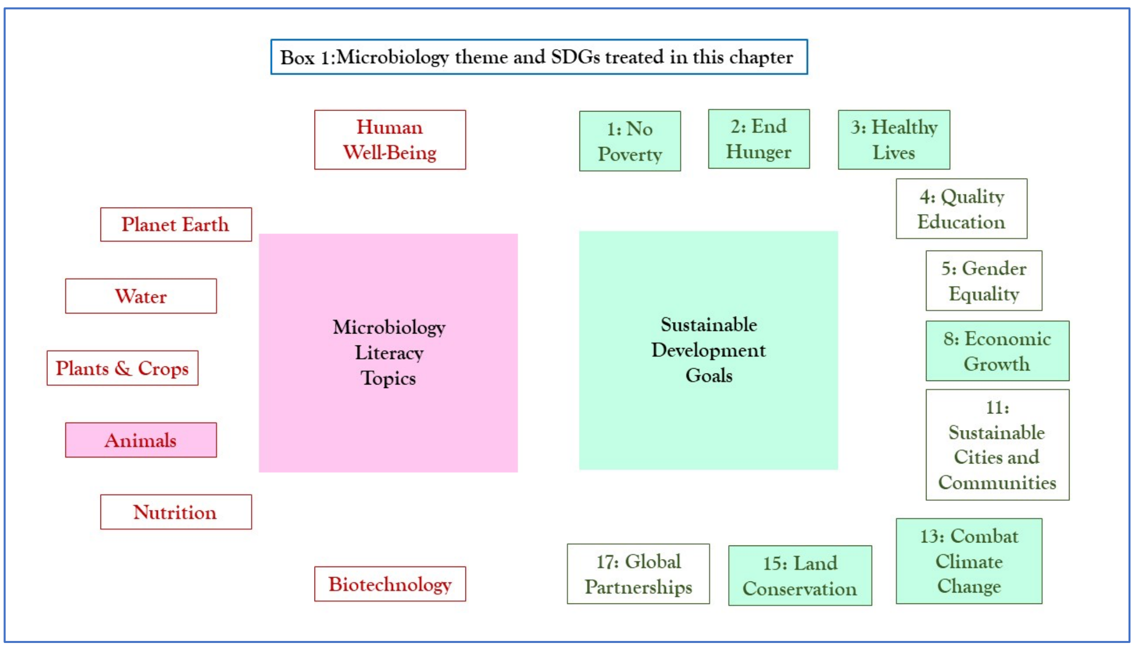
Fruit Flies

Storyline

Fruit flies represent a hugely diverse set of insect species in terms of genetics, habitat, behaviors, and food sources. Fruit flies have been a cornerstone of biology research for many years and have been used for many important discoveries in multiple areas including microbiology. One of these is that the fruit fly microbiome is known to play key roles in the health and development of flies. In addition, some fruit flies act as major agricultural pests that cause extensive damage to crops and cost billions of dollars worldwide each year to contain and monitor. Many flies, including invasive species, rely on microbes to help break down plant material into a form that is nutritious and digestible for flies, just as humans rely on our gut microbes to digest food. They are also pests more broadly in the food industry, and are a particular issue where they smell rotting foods. Some specific microbes infect flies and protect them from harmful predators and pathogens, and are also used in efforts to control agricultural pests and mosquito-borne diseases around the world. Fruit fly microbiology has an impact on a number of Sustainable Development Goals (SDGs).



The Microbiology and Societal Context

The microbiology: fruit fly diversity and role in agriculture and research; the Mediterranean fruit fly and the spotted wing *Drosophila* as agricultural pests; pectinolytic microbes as the source of food rot, and the role of other microbes in the health and development of flies; fruit flies as fruit flies and fermentation; fruit flies as vectors for plant (and maybe human) pathogens; microbes *Wolbachia* and *Spiroplasma*; control of fruit fly populations in agriculture and the home through microbial and non-microbial means. *Sustainable Development Goals (SDGs):* ending poverty; ending hunger and promoting sustainable agriculture; inclusive and sustainable economic growth; climate action; sustainable use of land

Fruit Flies: The Microbiology

1. Fruit flies include thousands of different fly species around the world, and some can destroy agricultural crops or act as valuable research tools. The term "fruit fly" is a broad one, covering over 4,000 described species around the world (Order Diptera, families Tephritidae and Drosophilidae). Despite all commonly being referred to as fruit flies, different species can be very distantly related. Indeed, some species last had a common ancestor tens of millions of years ago. For two of the most commonly studied species, *Drosophila melanogaster* (vinegar fly) and *Ceratitis capitata* (Mediterranean fruit fly), they last shared a common ancestor over 100 million years ago. For comparison, humans and chimpanzees are estimated to have last shared an ancestor about 12 million years ago. In addition, their life cycles, habitats, physical characteristics, and food sources can all vary dramatically from species to species (Figure 1). Indeed, the term "fruit fly" is inaccurate in that many species instead eat completely different foods, including mushrooms, flower nectar, or even bacteria on crab gills (Figure 2). In fact, the flies that commonly invade homes and kitchens represent a broad range of species, and could be attracted by rotting fruit, food stuck in sink drains, pet food, or even drink bottles.

Figure 1. Images of diverse fruit flies (Tephritidae and Drosophilidae). A) *Drosophila melanogaster*, B) *Chymomyza amoena*, C) *Drosophila silvestris*, D) *Drosophila hydei*, E) *Euarestra aequalis*, F) *Drosophila tristis*, G) *Rhagoletis suavis*, H) *Xyphosia miliaria*, I) *Urophora cardui*, J) *Anastrepha suspensa*, K) *Bactrocera dorsalis*, L) *Rhagoletis mendax*, M) *Drosophila suzukii*, N) Mycodrosophila *dimidiate*, O) *Zaprionus indianus*, P) *Stegana sp.*, Q) *Ceratitis capitata*, R) *Clusiosomina puncticeps*, S) *Terellia serratulae*, T) *Tephritis fermosa*, U) *Adrama austeni*, V) *Orellia falcata*, W) *Drosophila* larva, X) *Drosophila* female laying an egg on fruit. Image attributions below.

The two species that receive the most attention are *Drosophila melanogaster* and *Ceratitis capitata*. *Drosophila melanogaster* in particular is important because it widely used in scientific research as a model organism to study genetics, neuroscience, metabolism, microbe-host interactions, and many other foundational aspects of biology (Figure 2, and see topic "Animals/transgenic animals as experimental models for human:microbe interactions" for more detail; https://www.youtube.com/watch?v=qDbJnFLl3kU). In fact, research with this organism has led to critical discoveries in nervous system development and genetics, among other topics. *Ceratitis capitata*, meanwhile, is often considered the most agriculturally important pest in the world, as it is incredibly invasive and destructive of crops.

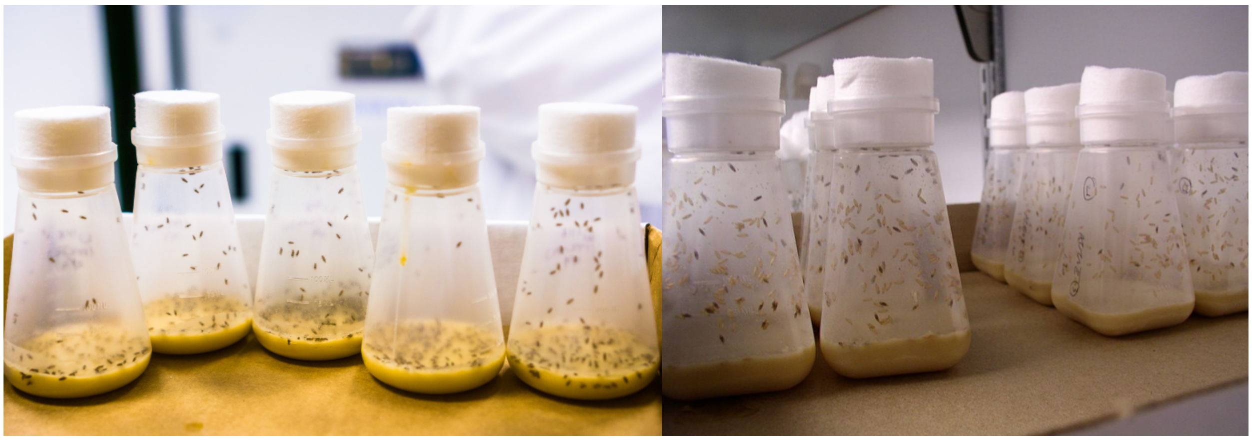


Figure 2. Fruit flies in a laboratory bottle containing food at the bottom. Flies live their entire lives in these bottles. Adults lay eggs in the food, the eggs hatch and the larvae eat lots of food. They ultimately climb up the walls of the container to turn into pupae, and emerge as adults. Left: Adults in food containers (Photo: Andreistanescu). Right: Pupae on walls of container (Photo: cudmore, CC BY-SA 2.0, via Wikimedia Commons).

2. There are many agriculturally important and devastating fruit flies, including the Mediterranean fruit fly and the spotted wing Drosophila (SWD). Fruit flies eat many of the same foods as humans, although most typically prefer to infest fruit that is already soft, rotting, and damaged and are therefore only minor nuisances (Figures 3 & 4). In contrast, some species are agricultural pests that infest and ruin huge amounts of our food supply because of various unique characteristics including the ability to infest food before it is rotten or overripe. Further, while most fruit fly species are adapted to a specific type of food or environment, invasive pests are often highly adaptive and can survive and reproduce using a huge variety of foods in a variety of contexts. It is these highly adaptable species, such as the Mediterranean fruit fly (also referred to as the medfly), *Zaprionus* species (such as the African fig fly), and *Drosophila suzukii* (spotted wing *Drosophila* or SWD), that are the greatest economic and agricultural threats. These pest species have multiple unique characteristics that make them significantly worse than many other species. First, they are highly adaptable to new food sources, so they are not limited to areas with specific crops. Specifically, the medfly is known to infest over 300 different varieties of foods (fruits, vegetables, and nuts), *Zaprionus* can infest over 80 different kinds of plants, and the SWD can infest dozens of varieties of soft-skinned fruits. Second, they are highly adaptable and invasive in new climates, allowing them to rapidly spread geographically. Indeed, these flies are found around the world, forcing governments and farmers all over the globe to enforce strict policies on import and export of foods to avoid further spread. Third, some flies have physical features that enable infestation of still ripening fruits that other flies typically avoid. For example, the SWD has a serrated egg-laying organ so that it can cut into ripening fruit easily to lay eggs. This makes SWD-infested foods harder to identify sometimes due to the lack of initial rot, which is typically a warning sign of infestation. Critically, not only are infestations of flies like these therefore hard to identify and treat, crops are also damaged or lost before they are ready to be consumed by humans. Further, foods unknowingly shipped with unidentified infestations allow the flies to spread. The economic and agricultural damage is huge. Crop loss alone costs the world billions of dollars annually, with ensuing government-mandated food screening and oversight to prevent their spread costing billions more. See this link for a video on the Queensland fruit fly in Australia: https://www.youtube.com/watch?v=HQgvrbTULTw.

Figure 3. Various fruit fly species on different food sources. A) Flies on fallen guava, B) Flies on rotting apple, C) Flies surrounding a mushroom, D) Flies on mushroom, E) Flies on pear, F) Flies on rotting wood, G) Fly on flower, H) Flies on rotting mango, I), Flies on rotting banana, J) Flies on rotting pears, with brown spots of rotting where flies feed and reproduce, K) Flies swarming a watermelon. Image attributions below.

3. Microbes play a critical role in the lives of fruit flies. Microbes are hugely important in many aspects of the lives and reproduction of fruit flies. The microbiome plays an important role in fly development and health. The activity of some microbes in *Drosophila* can increase or decrease developmental rate, alter lifespan, increase body size, activate energy metabolism pathways, help with proper regulation of the immune system, or even increase egg-laying. In fact, the microbiome can even affect behavior, with certain microbes regulating physical activity (microbe-free flies reared in labs are hyperactive), food and foraging behaviors (they often prefer food populated with microbes they already have and are familiar with), and even kin recognition and mate attraction. These are primarily done through microbial production of small molecules that either send signals directly to fly cells within the body, or that produce odors that are recognized by other flies. In addition, just as there are microbes that make humans sick, there are microbes that make flies sick. There is a wide variety of pathogenic bacteria, fungi, and viruses that can either broadly infect flies and other insects, or infect specific kinds of flies. This makes them good systems to study microbe-host interactions, as flies are easy and inexpensive to rear in the lab and there are many genetic tools available to study them. Further, despite their overall dissimilarity to humans, they have comparable innate immune systems, making them an excellent research organism to understand immunity.

4. Specific microbes help fruit flies infest food. Agriculturally, microbes play a critical role in rotting of food and destruction of crops (Figure 4). Among these are bacteria that fix nitrogen (called "diazotrophs", they convert environmental nitrogen into nutritious forms that flies can digest) and others that help break down plant material (called "pectinolytic", they can break down pectin sugars in plants). In particular, it is these pectinolytic microbes that are responsible for rotting in foods. Unripe and undamaged fruit are nutritionally challenging environments as a sole source of nutrition, even for flies. They are low in protein and high in sugars that cannot be digested by the flies. Microbes assist the flies in these environments by breaking down plant pectins into forms that are edible to flies, which is the cause of rotting spots since pectins are essential parts of plant cell walls. In addition, yeasts enter the food and ferment, providing additional protein nutrition for flies. This collective rot also softens the fruit, making it easier for the larvae to move.

These microbes come from different sources in different cases. Much of the time, environmental microbes will get inside of the plant as it overripens or through a damaged spot, and this will rot the plant through microbial breakdown of the plant cells and other processes that then attract flies. Some major pests have a big advantage since they do not always have to wait for this process to occur. Some of them are able to pierce the skin of fresh food that has not yet ripened or rotted. Then, environmental microbes are introduced both through the damaged area on the food, and from the pests themselves (Figure 4). Adult medflies, for example, will regurgitate some of their microbes from their guts onto the food, or pass microbes on via the reproductive organs when eggs are laid in the food. Adult females also smear eggs with antimicrobial compounds from their reproductive organs, which may favor the growth of beneficial microbes and kill other microbes. The microbes then thrive in the food source and break down the food into a fly-digestible form. This allows the larvae to swim and eat in the microbial food mixture and consume the microbes that then colonize their guts, continuing the cycle. If multiple mothers lay eggs in the same fruit, this can also result in mixing or sharing of their microbes among all offspring. The microbes and flies therefore have a complex, mutually beneficial relationship where flies carry and spread the microbes, while the microbes break down foods into forms the flies can eat. While this is beneficial for flies and microbes, it results in crop loss for humans.

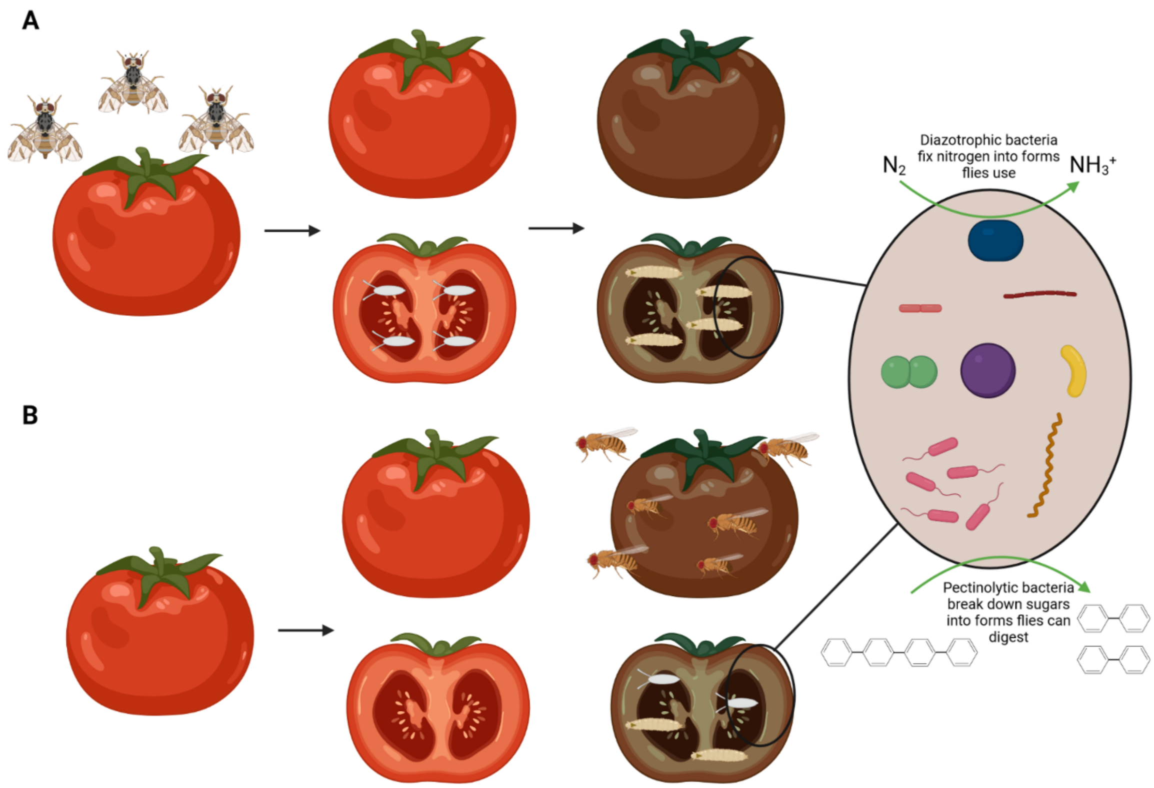


Figure 4. Summary diagram of relationship between flies, fruit, and microbes. A) Flies like medflies or SWD can pierce through unripened fruit to lay eggs. The damage from this allows environmental and fly-associated microbes to enter the fruit and rot it (brown), through processes including pectinolysis and nitrogen fixation. The products of the microbial chemical processes are then digestible and nutritious for the developing fly larvae. B) Alternatively, flies may wait until a fruit is naturally overripened over time or damaged, allowing microbes in. Then, microbes complete the same chemical processes that feed developing flies. Created in Biorender.com.

5. ***Fruit flies are attracted to the scent of fermentation, and can therefore affect a wide range of human foods.*** While some flies infest foods before they ripen, most species are attracted to a source that is already ripened and fermenting. Fermentation is a chemical process where microorganisms break down sugars or other organic substances in the absence of oxygen, which provides energy for the microbes. Flies lay eggs near the food or other moist organic materials, particularly where soft and over-ripened foods are damaged and allow easy access for larvae to feed. Flies smell the carbon dioxide that is produced by microbes during fermentation along with other odors, which attracts them to the food source. Different fly species will be attracted to different sources. Since flies simply look for moist, fermenting material, they are attracted to a huge variety of foods and places. They can be found in fruits and vegetables in fields, in the grocery store, restaurants, or in kitchens. Fruit flies are also found in garbage disposals and sink drains, garbage cans, liquid leftover from drink bottles, wet and dirty mops, pet food, wine, kombucha, beer, etc. This means that flies can be a nuisance not just in homes and farms, but are a major problem for food industries in general, especially producers of fermented food and drink. Importantly, this nuisance can be reduced through use of traps that use a variety of attractants (vinegar, sugar, etc.) to lure flies in and capture them so they are taken out of circulation. Different kinds of traps will work for different species, and it may be necessary to try out more than one to eliminate an infestation (traps with vinegar, yeast, fruit, etc.- Figure 5).

Figure 5. Different fruit fly traps are used in different situations. Left- sticky traps are common outdoors or indoors to physically prevent the flies from moving (Photo: Andras Csontos). Right top- vinegar traps are also commonly used indoors or outdoors by hanging an open drink bottle from a tree branch. The liquid is mostly apple cider vinegar with a few drops of dish soap. Paper funnels help prevent flies from escaping once inside (Photo: Joshua Rainey). Right bottom- once flies touch the soapy liquid, it sticks to them and they are unable to escape, and ultimately die. Captured flies are shown from a top view into this trap (Photo: Amrkl5).

6. ***Fruit flies can act as vectors of plant (and possibly human) diseases.*** Fruit flies are not directly harmful to humans, but research suggests they may vector pathogens that are harmful to plants or humans in certain circumsances. In lab tests, they can pick up common food pathogens like *E. coli*, *Salmonella*, and *Listeria* from fruits and vegetables and relocate them to another source, potentially posing a food safety risk. While it is unclear how much of a role fruit flies play in spread of foodborne pathogens outside of testing environments, it is possible they are involved. In addition, some species can carry plant diseases, for example, the oriental fruit fly that carries bacteria that can rot bananas. However, these bacteria are actually beneficial to the fly because they increase development rate and offspring hatching success. Many fruit flies are vectors of many different plant pathogens, making them unwitting vehicles of additional crop destruction beyond their own nutritional needs.

7. ***Bacterial symbionts of fruit flies can help flies survive in the wild, and some can also be exploited by humans to stop spread of infectious disease.*** Many members of the fruit fly microbiome play important roles in fruit fly health, as discussed above. In addition, some flies have specific microbes that can be beneficial. These microbes, such as *Wolbachia* and *Spiroplasma* bacteria, can have many positive effects on the host including increasing the egg-laying rates of females or increasing longevity. In addition, some strains of these bacteria help protect the flies against harm. Indeed, flies with *Wolbachia* become resistant to a lot of fruit fly pathogens, and *Spiroplasma* protect some fruit flies from predatory wasps that prey on the flies. In addition, since the bacteria spread themselves and fight other microbial pathogens, they are currently being used to fight mosquito-borne diseases as well. In fact, the *Wolbachia* strain from *Drosophila melanogaster* is currently being used to infect mosquitoes to make them resistant to viruses so that the mosquitoes no longer spread diseases to humans (see topic "Insects: The *Wolbachia* Story" for more details).

8. ***Microbial and non-microbial methods can be used to control fly populations.*** Fly population control can be done with various methods. For small infestations like home infestations, paper sticky traps can be useful, as can liquid traps using vinegar, fruit, or yeast (e.g. see https://lancaster.unl.edu/pest/resources/fruitflytrap.shtml). In agriculture, it is common to identify infested or possibly infested food and eliminate it. Farmers also commonly use pesticides, however, this may harm the environment and animals (see "Agrochemicals", "Plants and Insects", and "Plant Protection" topics for more details). Sometimes, male insects are reared in labs, irradiated to sterilize them, and then released into the wild to mate with females that then lay unfertilized eggs. This is called "sterile insect technique" or SIT. As stated earlier, there may be methods based on microbes as well. *Wolbachia* can also be used as an alternative to irradiation-based SIT or population suppression (see topic "Insects: The *Wolbachia* Story" for more details). For the major invasive agricultural pests, any infestation should not be handled by anyone except a professional authority, so it is advisable to contact the relevant governmental institute or authority in the area, which generally have protocols to properly prevent the infestation from spreading. See this link for a complete guide to indoor fly control: https://agrilifeextension.tamu.edu/library/insects/indoor-flies-and-their-control/.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of fruit flies in agriculture, research, and disease relates to several SDGs (microbial aspects in italics), including

- **Goal 1. End poverty in all its forms everywhere** (*reduce the economic effects of crop loss on farmers, reduce governmental funding required to monitor, increase food availability and drop food prices*). Some species of fruit flies cause massive agricultural damage, leading to billions of dollars' worth of crop losses every year. In addition, the costs of governmental overview can be equally costly, with many governments spending billions on programs to eradicate infestations of invasive species and also to sort and inspect food for signs of infestation. This can have a hugely detrimental effect on the farmers who grow the crops, and is a burden on the broader economy. In addition, it can drive up food costs when large losses are suffered.

Using various methods, including microbe-based control techniques, could be key to preventing these losses and expenses.

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture** (*reduce crop losses, increase the supply of nutritious whole foods*). As explained above, fruit flies lead to loss of crops. This not only affects the economy, but can cause problems in the food supply if large proportions of particular food types are infested or require quarantine measures. In addition, the crops affected by fruit flies are largely fresh, whole foods that are highly nutritious, which is an additionally difficult aspect of the losses. Crop infestations also lead to use of additional pesticides, which can have cascading environmental effects and is not a sustainable form of agriculture. In addition, the microbial pathogens that fruit flies carry have additional devastating effects on crop health and productivity.
- **Goal 3. Ensure healthy lives and promote well-being for all ages** (*use of symbionts to reduce disease spread*). As stated in point 8 and the topic "Insects: The *Wolbachia* Story", the *Wolbachia* strain in *Drosophila melanogaster* may be key to initiatives to stop the spread of infectious diseases by mosquitoes. See the *Wolbachia* topic for more detail. As it is possible that fruit flies may vector food-borne pathogens, it is possible they play a role in spreading these microbes as well.
- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all** (*promote economic growth and reduce agricultural economic burdens, sustainable employment for agricultural workers*). Fruit fly infestations in agriculture and the food industry result in large economic losses, and mitigation efforts are also costly. Farmers and others in the food industry can suffer greatly when crops or products are infested. There are further financial strains on governments that must monitor and manage infestations, and inspect food imports and exports to prevent spread of invasive pests. Prevention of infestations would lighten these large economic burdens and promote greater growth and job sustainability in agriculture and food.
- **Goal 13. Take urgent action to combat climate change and its impacts** (*achieve sustainable agricultural practices*). Climate change is expected to increase temperatures around the world. As fruit flies prefer warmer climates, even species that are already highly adaptable will continue to spread, bringing with them additional devastation to agriculture through the spread of plant diseases and direct fly infestations. On top of other potential effects on agricultural productivity due to rising temperatures, fruit flies may make matters worse. This may lead to increasing use of pesticides, and will make sustainable agriculture more difficult.
- **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** (*reduce the effects of pesticides, reduce the demand for additional land for agriculture*). As fruit flies continue to destroy crops and the human population grows, there will be an expanding need for additional land to increase food production and expanding use of pesticides. This will result in loss of wild land to use for agriculture, and an ensuing loss in biodiversity. Alternative measures to control pests without pesticides, such as *Wolbachia*-based techniques, may be key to achieving sustainable ecosystem management.

Potential Implications for Decisions

1. Individual

a. Considering the use of various methods to control infestations in a home, business, or garden (which kind of control method to use? should any pesticides or traps be used, or can the source of the infestation be removed? Note that invasive species infestations should be handled by an approved authority only, as individuals may accidentally spread the pest or not completely clear it).

b. Consequences of pesticide use on other nearby plants (it will impact additional insects, plants, and animals)?

c. Methods of quarantining diseased plants (will fruit flies spread the disease, and should they be blocked from access to the plant)?

2. Community policies

a. Local consequences of pesticide use (environmental effects, ecological impact)

b. Local buy-in to alternative strategies like *Wolbachia* control (ecological impact of fly population suppression, cost of various methods)

c. Land allocation and use for agriculture vs other activities

3. National policies

a. Regulations on pesticide use (which ones, in what contexts, considering environmental impact vs agricultural impact).

b. Investment in alternative control methods, research and development (SIT or *Wolbachia* methods?)

c. Policies for monitoring, inspecting, and managing invasive pests and imports/exports of foods

d. Quarantine policies and methods for fruit fly-vectored plant diseases

e. Acceptable land use practices, expansion of agricultural needs with global warming or pest spread

Pupil Participation

1. Class discussion of the issues associated with fruit flies- what are the positives and negatives? Consider research importance, role in the environment (invasive vs non-invasive, possibility of pollination, etc.), and effects on agriculture and the economy.

2. Pupil stakeholder awareness

a. Fruit flies can be important parts of ecosystems, or they can be destructive invaders. What are the positive and negative consequences of various fruit fly control methods in the home and in agriculture for different kinds of flies?

b. What measures are in place in your country to monitor and manage pest infestations? Can you think of additional measures that could help prevent infestations?

c. What would you do if you discovered a fruit fly infestation in your garden?

3. Exercises

a. What are the various advantages and disadvantages of different kinds of fruit fly control methods?

b. What can individual farmers do to minimize the potential for crop loss due to fruit fly infestations? What additional challenges may farmers face in the long term in protecting their crops? Consider both preventative measures and treatment measures.

c. Considering that fruit flies are attracted to fermentation, what places or industries can you think of that may be affected by fruit flies? What preventative measures can be taken in these cases?

d. Find a major scientific advance that occurred because of research on *Drosophila*.

The Evidence Base, Further Reading, and Teaching Aids

Mediterranean fruit fly, Zaprionus invasive species, and spotted wing Drosophila (SWD)

Sela, S., Nestel, D., Pinto, R., Nemny-Lavy, E., & Bar-Joseph, M. (2005). Mediterranean fruit fly as a potential vector of bacterial pathogens. *Applied and Environmental Microbiology*, *71*(7), 4052-4056. https://www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/the-threat/med-fruit-fly/med-fruit-fly

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Fruit fly microbes and food infestation (pectins, diazotrophs)

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Behar, A., Jurkevitch, E., & Yuval, B. (2008). Bringing back the fruit into fruit fly–bacteria interactions. *Molecular Ecology*, *17*(5), 1375-1386.

Fruit flies, fermentation, and fly traps
https://lancaster.unl.edu/pest/resources/fruitflytrap.shtml

Fruit flies and plant pathogens, human pathogens
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Black, E. P., Hinrichs, G. J., Barcay, S. J., & Gardner, D. B. (2018). Fruit flies as potential vectors of foodborne illness. *Journal of Food Protection*, *81*(3), 509-514.

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J. Anastrepha suspensa- Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services, Public domain, via Wikimedia Commons
K. Bactrocera dorsalis- Scott Bauer, USDA Agricultural Research Service
L. Rhagoletis mendax- Jerry A. Payne, USDA Agricultural Research Service, CC BY 3.0 <https://creativecommons.org/licenses/by/3.0>, via Wikimedia Commons
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W. *Drosophila* larva- Photo by David Duneau.
X. *Drosophila* laying egg- Photo by David Duneau.

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A child-centric microbiology education framework

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Glossary

- Adapted: when an organism has adjusted to the conditions of a new context or environment
- Antimicrobial Compound: a molecule that kills microorganisms or stops their growth, such as an antibiotic
- Biodiversity: the variety of life in the world or in a particular habitat or ecosystem
- Carbon Dioxide: a colorless, odorless gas produced by natural processes like breathing or fermentation
- Cell Wall: a rigid layer of sugar molecules on the outside of the cells of organisms like plants
- *Ceratitis capitata*: scientific name for Mediterranean fruit fly
- Climate Change: a change in global or regional climate patterns, in particular due to increased levels of carbon dioxide produced by use of fossil fuels
- Common Ancestor: the last shared ancestor that two species had in common before diverging into multiple species long ago in evolutionary timescales
- Diazotroph(ic): microbes that can fix nitrogen in the atmosphere into a form that is usable by other organisms
- *Drosophila melanogaster*: the common vinegar fly, broadly used in scientific research
- Fermentation: is a chemical process where microorganisms break down sugars or other organic substances in the absence of oxygen, which provides energy for the microbes
- Genetics: the DNA-based heritable properties of an organism
- Innate Immune System: the first line of defense against pathogens, including non-specific antimicrobial barriers and molecules that have general defensive ability against many different microbes (as opposed to the adaptive immune system, which does not exist in flies)
- Invasive: plants or animals that spread prolifically and harmfully beyond their natural geographical area
- Medfly: short term for Mediterranean fruit fly, or *Ceratitis capitata*
- Mediterranean Fruit Fly: Common name for the medfly *Ceratitis capitata*, an invasive pest species that causes great agricultural damage
- Metabolism: chemical processes that occur within a living organism to maintain life
- Microbiome: colloquially (as it is used in this document), the microorganisms of a defined organism or environment (strictly scientifically, it refers to the specific genetic material of said organisms)
- Model Organism: a species that has been studied widely usually because it is easy to maintain and breed in a lab setting and is particularly suitable for studying some desired trait, disease, or biological process
- Molecules: groups of atoms bonded together to form a compound
- Organic: relating to or derived from living matter
- Pathogen: a microorganism that can cause disease
- Pectin: a sugar in plants that is a key component of cell walls
- Pectinolytic: the trait or property of a microorganism or molecule to metabolize or break down pectin sugars into smaller molecules

- Pesticide: a substance used to destroy insects or other organisms harmful to cultivated plants or animals
- Species: a group of organisms consisting of similar individuals capable of exchanging genes or interbreeding
- Spotted Wing *Drosophila* (SWD): an agriculturally important fruit fly pest species, scientific name *Drosophila suzukii*
- Sustainable/Sustainability: conserving an ecological balance by avoiding depletion of natural resources
- Sustainable Development Goals (SDGs): 17 goals set by the United Nations in 2015 as part of an agenda for sustainable development around the world
- Vector: an insect or other organism that transmits diseases from one animal or plant to another