CHAPTER 2

Identification and Diagnosis of Plant Pests and Diseases

In this chapter you will learn the meaning of biotic and abiotic (and what may confuse you), what a pest is, how insects (and mites) can be good or bad, the life cycles they have, and consider the symptoms that help to identify them. You will also learn about plant pathogens, the diseases they cause, and their symptoms.

What equipment do I need?

- ✓ **Pre-prepared PowerPoint presentation to cover Sections 2.3-2.8**
- ✓ **Plastic bags**
- ✓ **Marking pens**
- ✓ **Hand lenses**
- ✓ **Samples of pests and diseases, enough for one per trainee**
- ✓ **Laminated pictures of plant pests and diseases:**
    - **A, B & C**
- ✓ **Pacific Pests, Pathogens & Weeds app:**
    - **fact sheets**
    - **mini fact sheets**
- ✓ **3 tables marked A, B & C**
- ✓ **Brown or butchers' paper**
- ✓ **Sticky tape**

2.1 Introduction to identification and diagnosis

Many farmers and extension staff find it hard to identify pests and diseases that attack crops[4]. However, without knowing the cause of the damage seen in the field, it is difficult to know what to do for the best. Often, damage from disease is mistaken for damage from insects, and vice versa. Sometimes the cause is not even a pest or disease, but an abiotic factor. Without good identification and diagnosis, guesses may be made which can result in the wrong management being suggested, such as too much pesticide or the wrong pesticide. Sometimes, nothing is done because of the confusion.

The damage to crops caused by pests and diseases and other factors appear as **symptoms** (or **signs**). These are very important as they help identify the cause of problems

So, what can we do? We can get an idea of the cause of crop pest and disease problems by looking at the damage – the **symptoms or signs** on the plant. This is exactly what the doctor does when you go to a clinic. The doctor examines you, looks at the symptoms and asks questions. In a similar way, a plant health doctor has to find the cause of a problem by examining the plant, looking at the symptoms and asking questions. Obviously, in this case the farmer answers the questions as the plants cannot speak for themselves!

To become proficient plant health doctors, trainees need to spend a lot of time becoming familiar with the plant pests and diseases in their countries. ***There is no substitute for experience!*** The trainees need to know how to examine plants carefully with the help of a hand lens, recognise symptoms, and make use of resources, such as the Pacific Pest, Pathogens & Weeds app.

[4] Sometimes the terms 'pest', 'disease' and 'pathogen' are confused or used interchangeably. Diseases in plants are caused by pathogens (infectious organisms), as well as environmental conditions (abiotic or physiological factors). Pests, such as insects and mites, affect plant health by chewing or sucking. Weeds are also sometimes included as 'pests'. *In this manual we use the word 'pest' to include insects, mites, other animals and weeds, and the word 'disease' to include pathogens, i.e. fungi, oomycetes, bacteria, viruses, nematodes, phytoplasmas and viroids.*

2.2 Field diagnosis of plant pests and diseases – A, B or C[5]

Identification and diagnosis of problems during farm visits and at plant health clinics have to be done without the use of specialised equipment like that used in a laboratory. How can it be done and what is involved?

First, trainees need to sort the problems that can occur in the field into different categories. One way of doing that is to sort them into causes that are: (i) non-living; (ii) living; and (iii) not sure or confused. We can call these Abiotic (A), Biotic (B) and Confused (C), or A, B and C, respectively (Table 2.1 and Figs. 2.1 & 2.2).

Abiotic factors are non-biological. Like people and animals, plants get sick, not just from pests and diseases but also from non-biological factors; these we call 'abiotic'. For plants, these can include unhealthy environments such as poor soil, devasting weather, chemical poisons, or damage during cultivation. Sometimes it is difficult to differentiate between abiotic and biotic damage, as the symptoms can look quite similar. Also, a variegated but healthy leaf can be diagnosed as having a disease or a nutrient deficiency, whereas variegation is a genetic condition where chlorophyll is absent from part of the leaf.

Table 2.1 shows the main abiotic factors that can cause problems in plants. Of these, perhaps the most important are poor soil structure and composition, and nutrient deficiencies.

Table 2.1 Different categories that make up abiotic and biotic causes. 'Confused' can be when there could be more than one cause, or you don't know what it is.

Abiotic – non-biological causes	Biotic – biological causes
Nutrient deficiencies	Insects
Drought (water stress)	Mites
Waterlogging	Birds
Root damage from ploughing, hilling up, etc.	Snails and slugs
Fertiliser burn	Rats and mice
Herbicide damage	Parasitic plants, e.g. *Cuscuta* (dodder), mistletoe
Salt spray	Weeds
Lightning Frost, e.g. in the highlands of PNG Sunscald Very hot weather Senescence (old age)	Pathogens: • fungi • oomycetes • bacteria • nematodes • phytoplasmas • viruses and viroids

[5] This exercise is adapted from Plantwise PHC course Module One. The examples in the manual have been adapted to the Pacific context. See https://blog.plantwise.org/2017/10/25/using-the-plantwise-training-modules-and-approach-to-strengthen-the-curriculum-at-ucatse/

2.2.1 Abiotic causes

Poor structure and composition of soil

While plants have different soil requirements, there are some basic needs for optimum growth. In general, what we call ‘healthy soil’, is soil that can hold water and air, is not too fine or too coarse so it avoids waterlogging or drying-out too quickly, and contains a good amount of organic matter and some clay to hold nutrients. It also has a large number of macro- and micro-organisms, such as earthworms, bacteria, fungi and nematodes to keep it aerated and help nutrients became available to plants. Healthy soil has a pH of around 6 to 7, which is best for most plants, although many require a lower or higher pH. Just as humans are less likely to get ill if they have a healthy diet and lifestyle, plants growing in healthy soil are less likely to be attacked by pests and diseases.

Nutrition

Although they make their food (sugars) through photosynthesis from carbon dioxide and water, in order to be healthy, plants also need a range of other nutrients which they must get from the soil though their roots. If some of these nutrients are missing, the plant will show nutrient deficiency symptoms. Too much of a nutrient may also cause problems. Nutrient deficiency symptoms can be confusing; usually they appear as yellowing or discoloured patches on the leaf. The veins might also be discoloured or the fruit might be small, misshapen or fail to ripen. Sometimes there are no symptoms at all except a reduction in yield. In general, nutrient deficiency symptoms on the leaf form a pattern that is evenly spread, whereas disease symptoms tend to be patchy.

The most common nutrient deficiencies in Pacific islands are lack of nitrogen, potassium, sulphur, phosphorus, calcium, magnesium and chlorine. These are the macronutrients - needed in quite large amounts. Manganese, boron, zinc, cobalt, iron and copper are micronutrients, needed in smaller amounts. Sometimes it is difficult to know if the problem is a lack of the mineral in the soil or the plant is under stress and cannot take up the mineral properly, even if it is present. This is the case in blossom end rot of tomato and zucchini, as the disease is especially common when rapidly developing fruits are exposed to drought. The roots cannot transport enough water and the fruits rot from the flower end.

If possible, have a soil test done to find out what is missing in the soil. Then fertilisers can be applied that add the missing nutrients. Some governments (e.g. Fiji) provide soil analysis if farmers make requests through the extension service.

Abiotic

Fig. 2.1 Some abiotic conditions on common crops in Pacific island countries.

2.2.2 Biotic causes

The biotic group is very large, so we split it into smaller groups in the hope that the **symptoms (signs)** we see in the field will give us clues to the type of organisms that are causing the damage. For instance, insects can be split into those that chew, those that suck, and those that pierce (see Table 2.2 and Figs. 2.5.1-2.5.3).

Pathogens can be split into those that cause spots, blights, rusts, wilts, mildews, and more (Figs. 2.79-2.90). The idea is to match the symptoms we see with the damage we associate with different types of organisms as closely as possible.

Of course, we must have some idea about the different symptoms these groups cause in the first place, and that comes down to experience and practice. The manual sections 2.4 (Insect life cycles), 2.5 (Symptoms of insect and mites), 2.6 (What is a plant disease?), and 2.7 (Symptoms of pathogens), will help you by providing information, and 2.9 (Making a diagnosis: symptoms, possibilities, and probabilities) will give you the opportunity to put the learning into practice.

Once we have identified the likely cause of the damage, we say we have made a **diagnosis**. Then we can go on to recommend a treatment.

2.2.3 Confused

But what do we do if we are confused? A plant health doctor might be confused because the farmer presents a plant with symptoms that: (i) may be caused by more than one pest or disease; (ii) the doctor is unsure of; or (iii) are new to the doctor (Fig. 2.2).

It takes a lot of time and experience to become good at diagnosing symptoms, and even experts do not always know the cause of a plant problem. There are a lot of resources to help, and this manual will help your trainees to become familiar with:

- Using a WhatsApp group
- Pacific Pests, Pathogens & Weeds app - Full and Mini fact sheets
- PestNet Community

If the problem is still confusing or unknown, samples will need to be sent to the agencies in each country that deal with pest and disease identification, i.e. research or biosecurity. It may even mean that samples (or photographs of samples) need to be sent overseas for examination. Further information on these aspects is given in Chapters 3 and 6.

Fig. 2.2 When symptoms suggest the damage is caused by more than one pest or pathogen, or is something new to the plant health doctor or seen in the country for the first time, it is called "confused or unknown".

EXERCISE 1: A, B, C?

This exercise helps your trainees to begin to apply their learning to describe plant damage as abiotic (A), biotic (B) or confused (C) - either a mixture of symptoms or unknown.

In groups, allocate one or two sets of photo sheets of Pacific island pests and diseases. For each photo, trainees should decide whether the damage is caused by **abiotic** (A) or **biotic** (B) factors, or if unsure, **confused** (C).

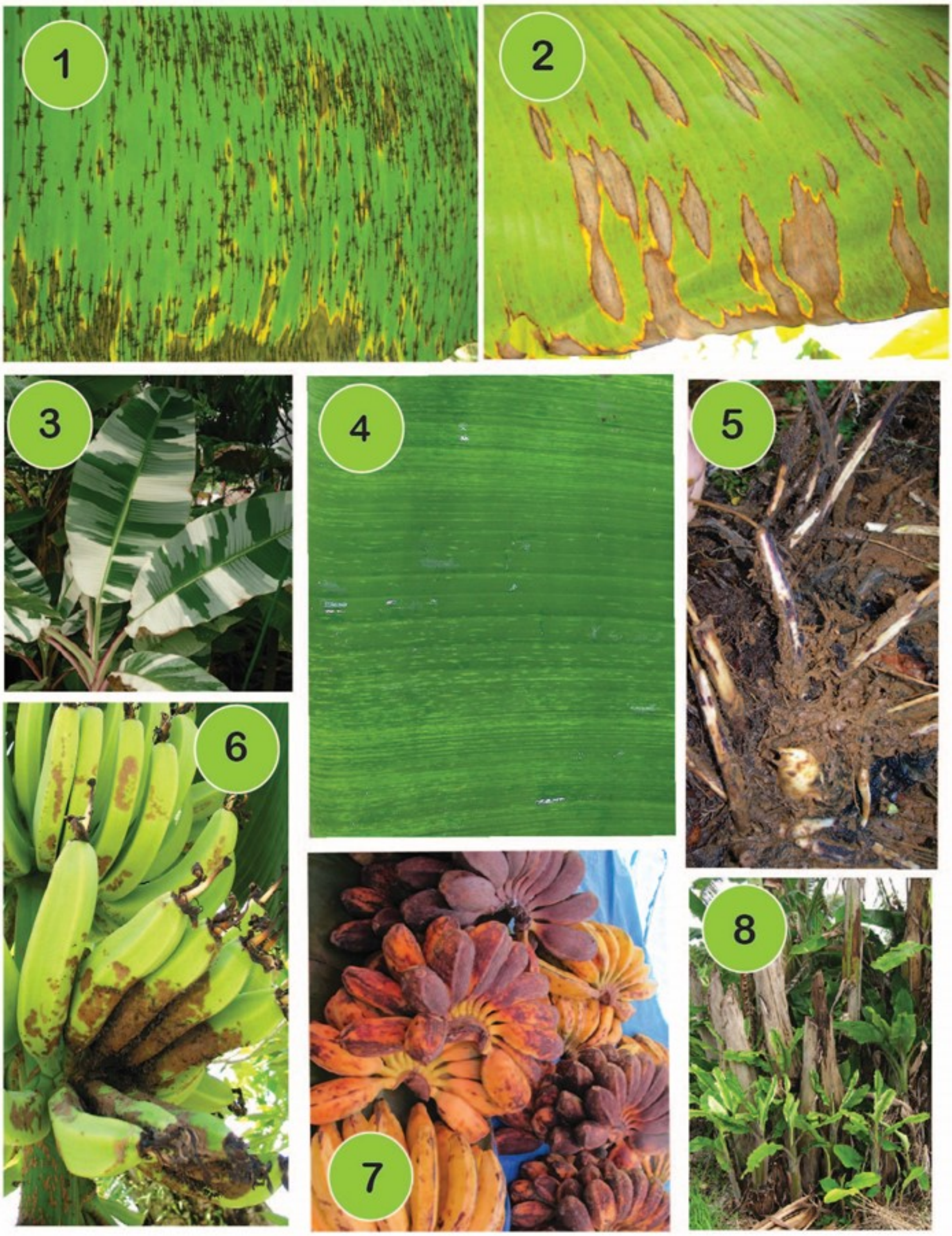
Fill in the table for the A, B, C photosheets. Trainees will need to draw a separate table for each photosheet. Trainees should give reasons and present their answers to the rest of the class. *Go through the answers first before asking them to fill in the last column.*

Your answers

Crop	Photo	A, B or C?	Reasons	Correct answer (fill in after class discussion)
	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			

BANANA

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?

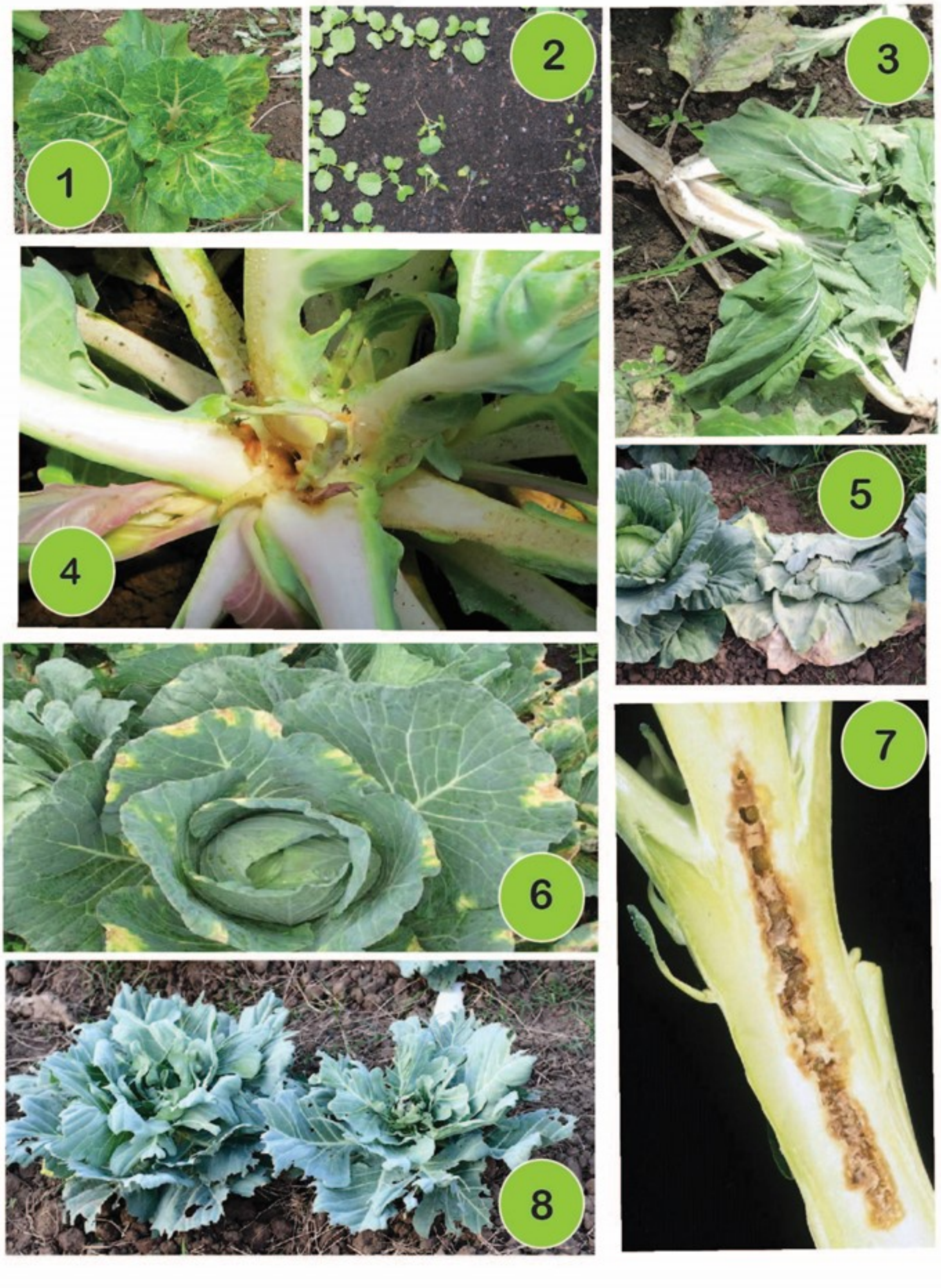


BELE

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?

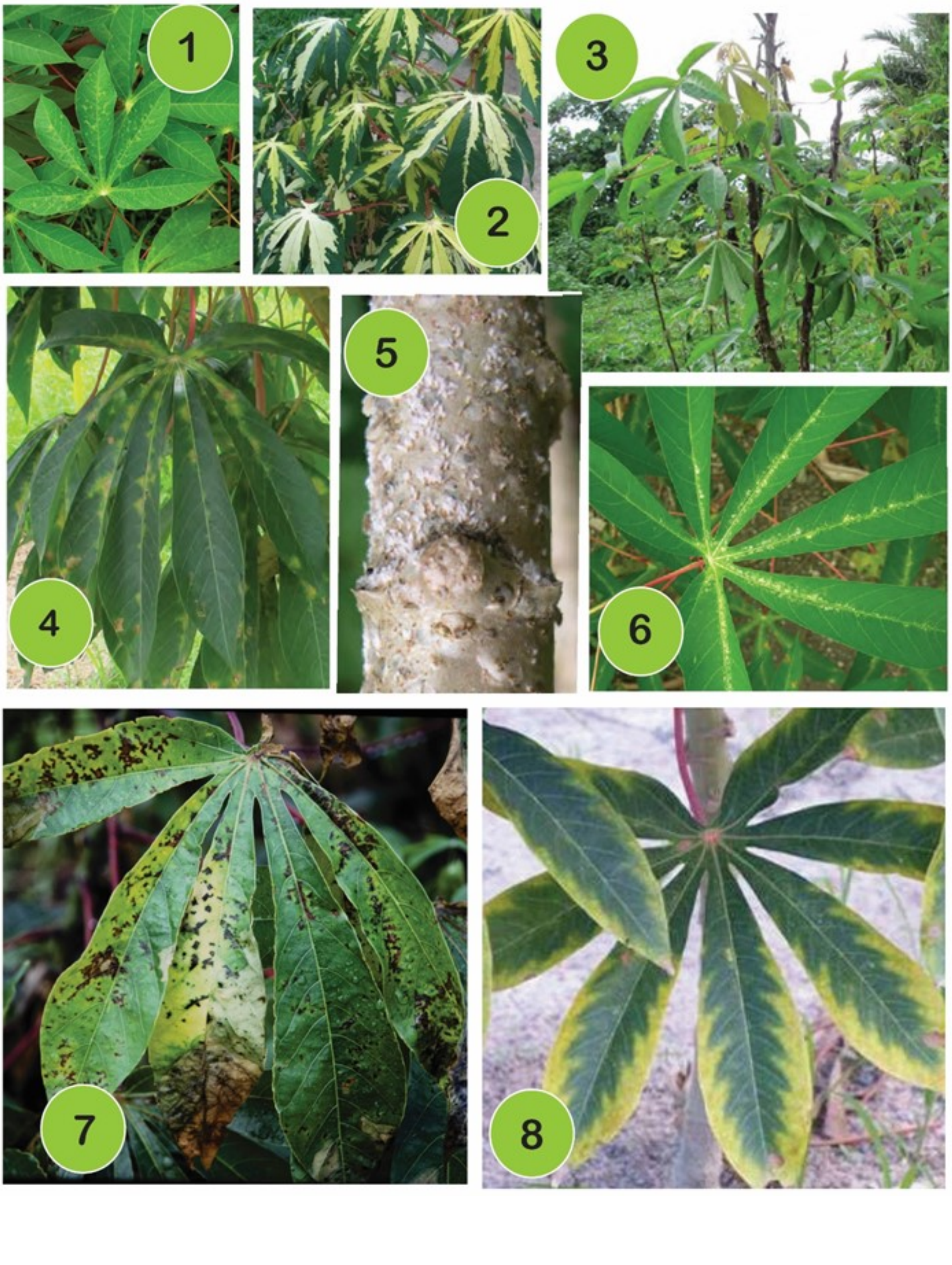
CABBAGE

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?



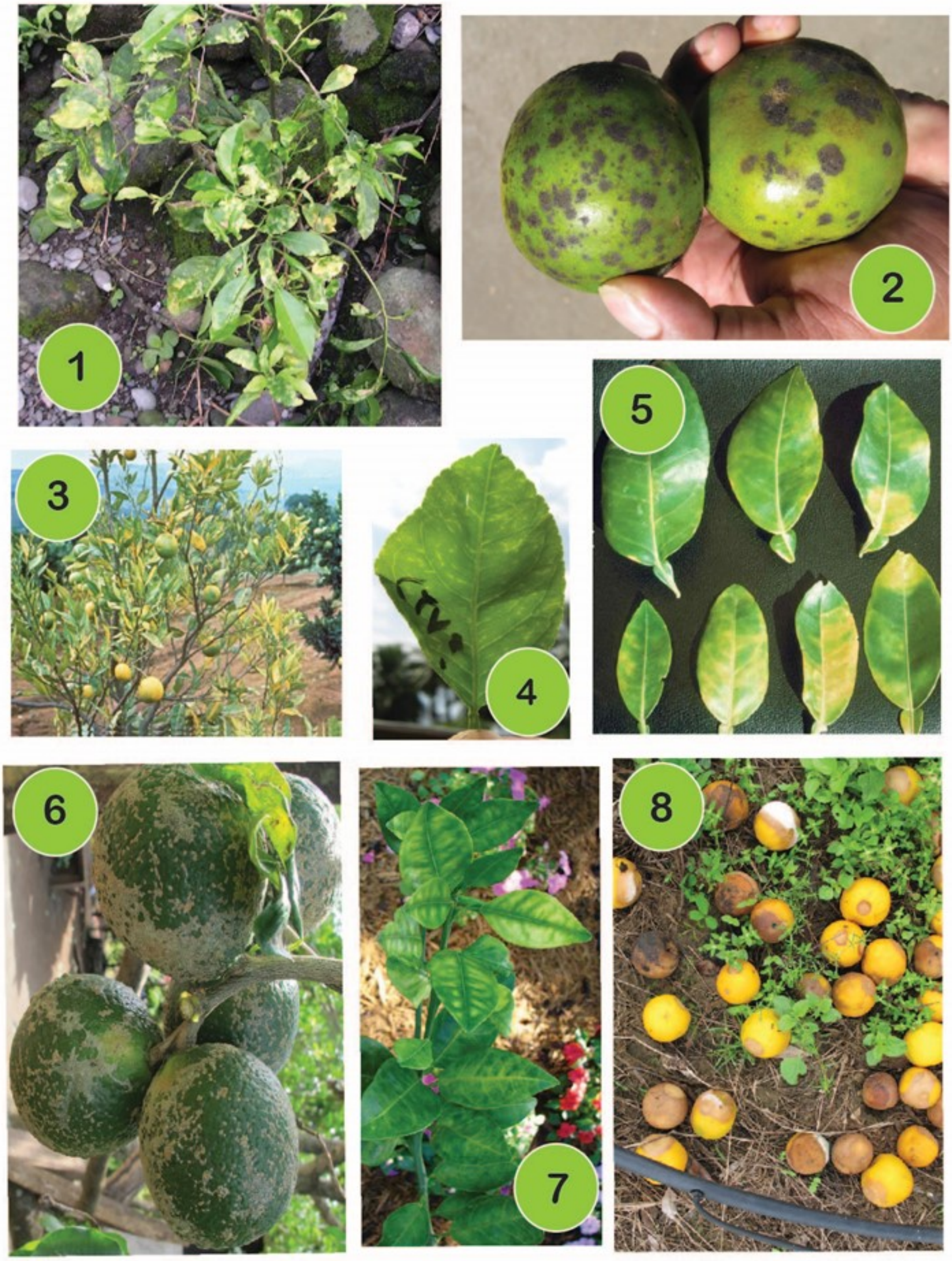
CASSAVA

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?



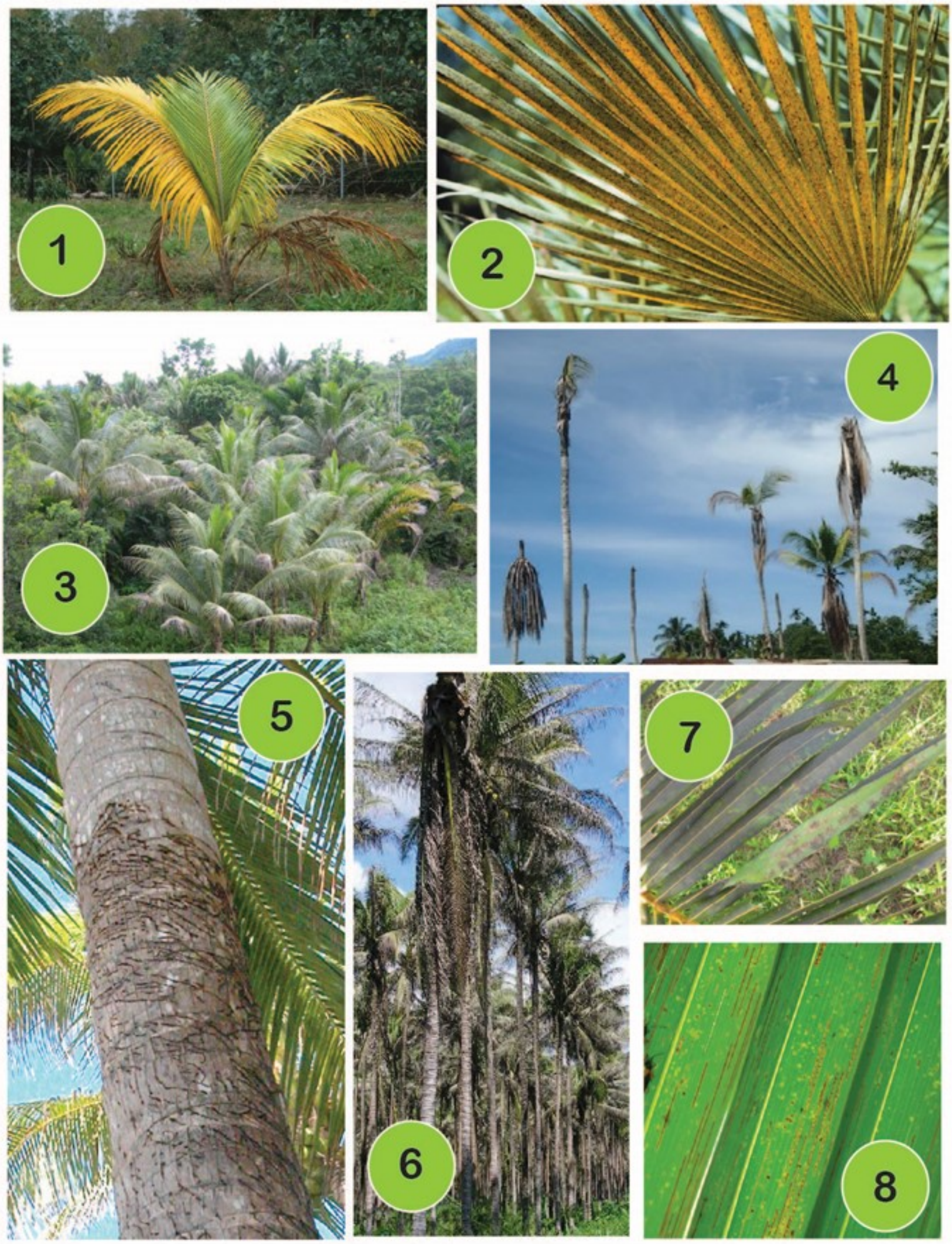
CITRUS

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?



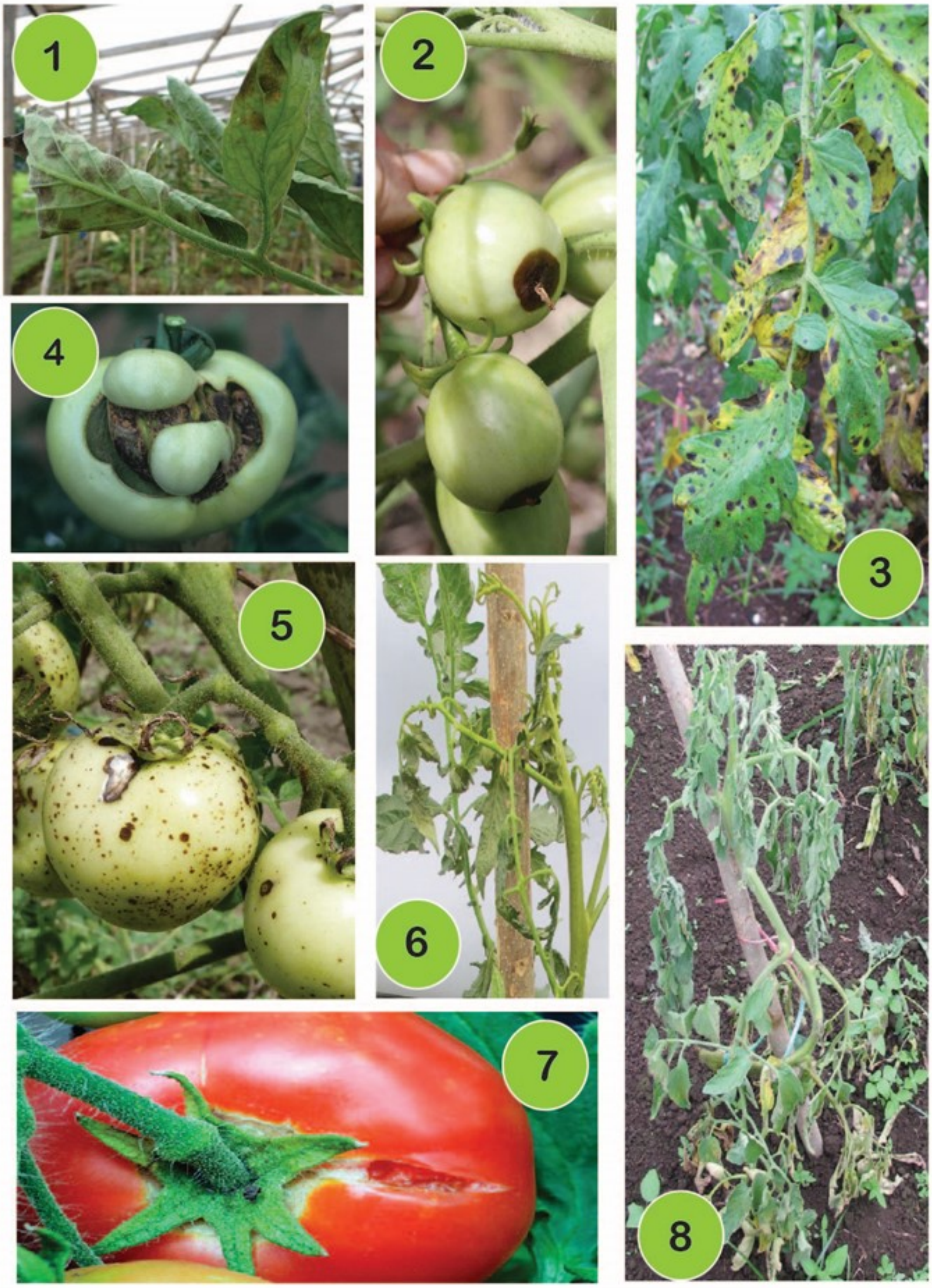
COCONUT

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?



TOMATO

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?



MIXED

Are these symptoms caused by something abiotic (A), biotic (B), or confusing (C)?

EXERCISE 2: Speed dating

This exercise is fun and helps your trainees practise identifying and describing symptoms on plants carefully and accurately. Ensure that they have enough samples of pests and diseases for one per trainee, and that you have set up three tables marked A,B and C.

Trainees should form two lines facing each other so they are standing opposite a partner. Give each person a sample of a plant pest or disease. One trainee carefully describes the symptoms to their partner ('date') opposite, and then both try to decide whether the cause is abiotic (A), biotic (B), or confused (C).

Trainees have two minutes. When you say "Stop", the other partner has to repeat the process with another sample. Next, everyone in one line moves to the left to a new partner, and repeats the process of describing the symptoms.

Trainees now place their samples on a table marked A, B or C, depending on what they think the cause is.

Now go through the next sections (2.3–2.8) of the manual with your trainees. You could create a PowerPoint slide show if you have the facilities for this. Alternatively, if they have access to the information, ask your trainees to read the sections for homework.

When you have completed this, your trainees will have a chance to change their minds about A, B or C (Exercise 5).

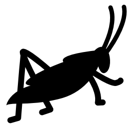
2.3 What is a pest?

In this manual we treat pests as organisms that you can see with the eye or with a hand lens. This includes insects, mites, slugs and snails, as well as larger animals, such as birds, mice, rats and even humans! Weeds are also regarded as pests. Most pests that farmers are concerned with are **insects** and **mites**. They usually cause problems by **chewing, sucking or, more rarely, piercing when laying eggs**. When they are on leaves, stems or flowers, they are quite easy to identify. It is more difficult to identify them on roots, unless there is obvious chewing, or the roots are decayed. For this reason, farmers often bring only the leaves to the clinic because that is where they see the symptoms.

Note: Insects[6] have **six** legs, except for some uncommon butterflies that have four. Mites belong to the arachnid class, along with spiders, scorpions and ticks, and have **eight** legs. Here are some important facts about insects/mites/spiders that will help identify them as plant pests.

There are 30 orders of insects, but only eight orders contain pests. The insects in these eight orders are listed below.

1. Grasshopper, crickets and katydids (Order: Orthoptera)
2. Moths and butterflies (Order: Lepidoptera)
3. Beetles and weevils (Order: Coleoptera)
4. Flies (Order: Diptera)
5. Termites (Order: Blattodea)
6. Ants, bees, wasps and sawflies – many of these are beneficial insects as well as pests (Order: Hymenoptera)
7. Thrips (Order: Thysanoptera)
8. Aphids, 'bugs[1]' (true bugs), leafhoppers, planthoppers, psyllids, mealybugs, scales and whiteflies (Order: Hemiptera)



[6] The word 'bug' is meant to describe an insect in the order Hemiptera, not just any insect. The Australian Museum notes that not all insects are bugs. There are many different forms, including aphids, hoppers, scale insects, cicadas and, confusingly, the 'true' bugs – stink bug, assassin bug, coreid bug, and many more. The 'true bugs' are a sub-order known as the Heteroptera.
https://australianmuseum.net.au/learn/animals/insects/bugs-order-hemiptera/ ;
https://australianmuseum.net.au/learn/species-identification/ask-an-expert/what-do-true-bugs-look-like/

The taxonomy of mites is still being researched. Of the six or so orders, the plant parasitic mites belong to the order Trombidiformes; this contains the spider mites (tetranychid) and those smaller mites (eriophyid) living in galls and buds.

There are both 'good' and 'bad' insects

Insects that are considered 'good' for humans are those that pollinate flowers, e.g. flies, bees, butterflies, moths and beetles. These are necessary for seed and fruit crops. There are also insects that prey on other insects. These predators can be generalists, e.g. some wasps and beetles, or specialists, e.g. parasitoids – wasps and flies that lay their eggs on or in a pest, and whose larvae eventually kill it.

'Bad' insects are those that are bad for humans. These include: ☺ ☹

- Crop feeders – many
- Carriers of human diseases, e.g. mosquitoes that carry the malaria parasite or the dengue fever virus
- Carriers of plant diseases, e.g. aphids, mealybugs, whiteflies and planthoppers transmit viruses
- Nuisances, e.g. fire ants that 'sting' people with secretions of formic acid, or mosquitoes that bite

Some insects and mites are both good and bad

Some insects and mites can be both good and bad. For example, some ants keep generalist plant-feeding insects away – they prevent butterflies and moths from laying eggs, and their larvae (caterpillars) from developing. At the same time, they leave sap-sucking insects like aphids and scales alone, as the ants feed on their sugary secretions (honeydew). In this way, ants defend the aphids and scales from predators. There are also species of predatory mites, which are available for farmers to purchase in some countries. They are usually used in greenhouses against spider mites.

Spiders are almost entirely beneficial, mites less so

There are some 45,000 species of spiders and, unlike insects, none of them eats plants. Spiders hunt their prey or spin webs to trap them. Their effect on small caterpillars (e.g. on cabbages), on leaf and planthoppers (e.g. on rice), and on insect pests feeding on many other crops, is often overlooked. The only bad thing about spiders is that they also prey on honeybees, butterflies and other beneficial insects.

Mites are related to spiders, but some are bad. The so-called spider mites are plant pests that cause silvering on many plants. They live commonly on the underside of leaves along the main veins. Webs are often present. The other bad mites are the plant parasitic eriophyid mites; some cause galls and others feed in buds, causing distortions to developing leaves and flowers. Rarely, eriophyid mites spread viruses, but none are known to do so in the Pacific region.

However, as with insects, not all mites are bad. There are species of predatory mites, which are available for farmers to purchase in some countries. They are usually used in greenhouses against spider mites, and they also eat small insects.

Although many people don't like them, spiders are not insects and they are good for our crops, so should be left alone

2.4 Insect life cycles

Insects have two different life cycles – either complete or complex metamorphosis ('holometabolous', where the immature stages are different from adults) or incomplete or simple metamorphosis ('hemimetabolous', where the immature stages are similar to adults).

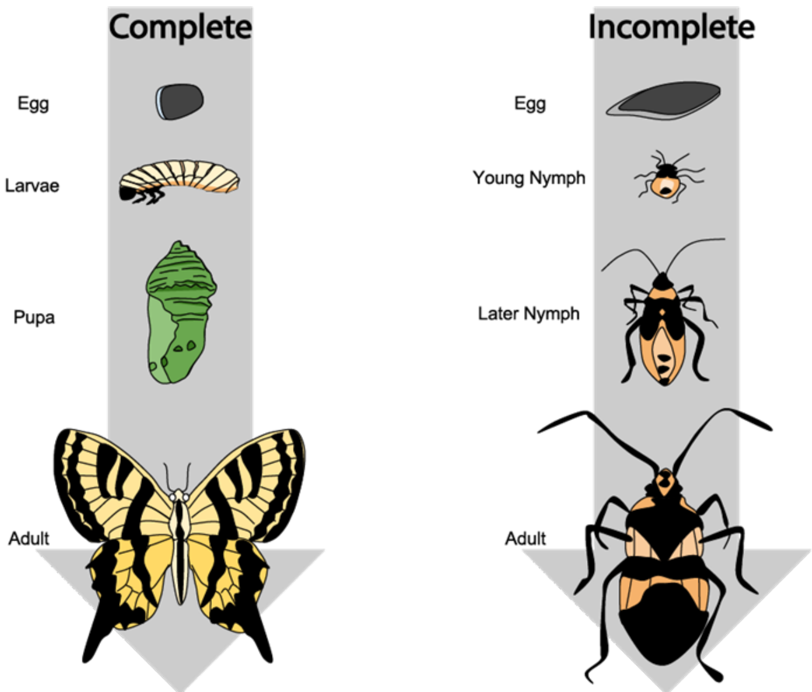


Fig. 2.3 Examples of complete and incomplete metamorphosis[7].

[7] Fig. 2.3 is adapted from an image courtesy of Wikimedia Commons, the free media repository and is available at https://commons.wikimedia.org/w/index.php?curid=49034418.

Life cycles of insects with complete metamorphosis

Insect groups that undergo complete metamorphosis are: Coleoptera (beetles); Lepidoptera (moths and butterflies); Hymenoptera (wasps, ants and bees); and Diptera (flies). All these groups have a life cycle where the egg hatches into a larva (e.g. a grub, caterpillar or maggot) that develops into an inactive pupa stage (or puparium in the case of flies) before emerging as an adult (e.g., a butterfly, beetle, wasp).

Life cycles of insects with incomplete metamorphosis

Typical insects that undergo incomplete metamorphosis are: Hemiptera (aphids, true bugs, cicadas, hoppers, mealybugs, scales and whiteflies); Orthoptera (grasshoppers and crickets); Blattodea (termites); and Thysanoptera (thrips). Immature stages of these insects are called nymphs, which gradually increase in size and change form. As the insects grow, they shed their skin (called moulting). After each moult, the nymphs look a little different or a little larger but, unlike a caterpillar of a butterfly or moth, the nymphs are not that different from the adults. After a final moult, the full adult form emerges (Fig. 2.3).

Life cycles of mites

Spider mites have four stages - egg, larva, nymph and adult. There is one larval stage with six legs and two nymphal stages that are small versions of the adult, with eight legs. The minute, carrot-shaped Eriophyid mites have three stages - egg, and first and second nymph. They have two pairs of legs.

Why is it important to know the life cycle of an insect pest?

Once you know which group your pest belongs to, the next most important step is to determine its life cycle. This allows you to suggest ways to control the pest at its most vulnerable stage, or possibly suggest how to avoid it all together. This is one of the basic concepts behind integrated pest and disease management (IPDM).

As we have seen already, insects have different types of life cycle, incomplete (simple) and complete (complex). Those insects with incomplete life cycles have nymphs that are similar to adults, which gradually change. They usually occur in the same habitat and eat the same food. For these, control strategies are the same for both stages. However, those insects with complete life cycles have larvae, pupae and adults that appear very different from each other and, importantly, often live in different habitats, eat different foods or, in the case of the pupa, do not eat at all. This means that controlling these insects may require a different response from insects with incomplete, simple life cycles.

Life cycles of the eight insect and single mite orders that damage crops are as follows (Figs. 2.4-2.18).

Grasshoppers, Crickets and Katydids

KATYDID
(unknown species)

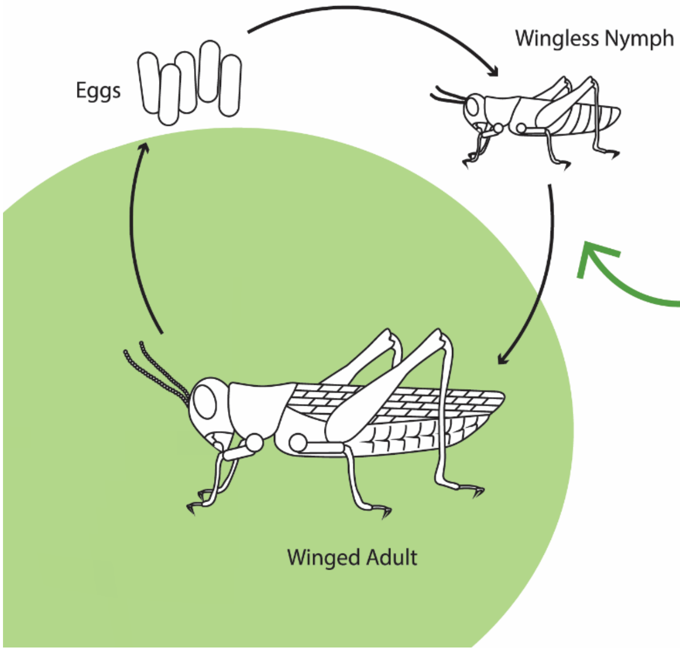
They have long antennae, longer than the body, and are often thin and thread-like. They also have very large hind legs. Most feed on plants.

GRASSHOPPER
(*Aiolopus* sp.)

Usually they have short antennae, shorter than the body length. They feed during the day. Most feed on plants.

CRICKET
(*Teleogryllus* sp.)

These have long antennae, but differ from katydids. They have long ovipositors, eat both plants and insects, and live in burrows in the ground during the day.

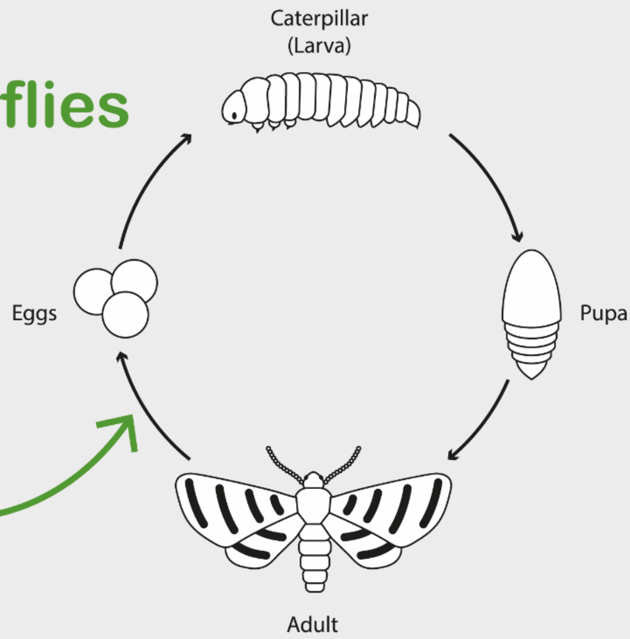


These have simple life cycles. Eggs laid in the soil, hatch into small versions of the adult, gradually getting larger by successive skin shedding (moults). Small wing-buds can often be seen, and these get larger after each moult. There is no resting stage. The adult has fully developed sex organs, and wings may be fully developed, but in many species wings are short or absent.

Fig. 2.4 Life cycle of grasshoppers, crickets and katydids (order Orthoptera).

Moths and Butterflies

These have complex life cycles. Eggs are laid singly or in groups, usually on plants. A larva hatches and gradually gets larger as it passes through several skin changes or moults. Finally, it forms the non-feeding pupa (resting stage). The pupa may be on a plant or in the soil. The pupa stage ends with the emergence of the adult.



Adult moths and butterflies usually feed on plant nectar, but there are rare exceptions, e.g., the fruit piercing moth, which sucks juice from fruits. Adults (not caterpillars) are used by taxonomists to categorise them. This is a *Diaphania* sp. adult.

Moths and butterflies differ:
i) while at rest, adult butterflies fold their wings, while moths spread theirs flat;

ii) the antennae of adult butterflies end in club-like tips, while moth antennae are feathery;

iii) moth pupae are wrapped in a silk-like covering, whereas butterflies' pupae are hard, smooth and without silk.

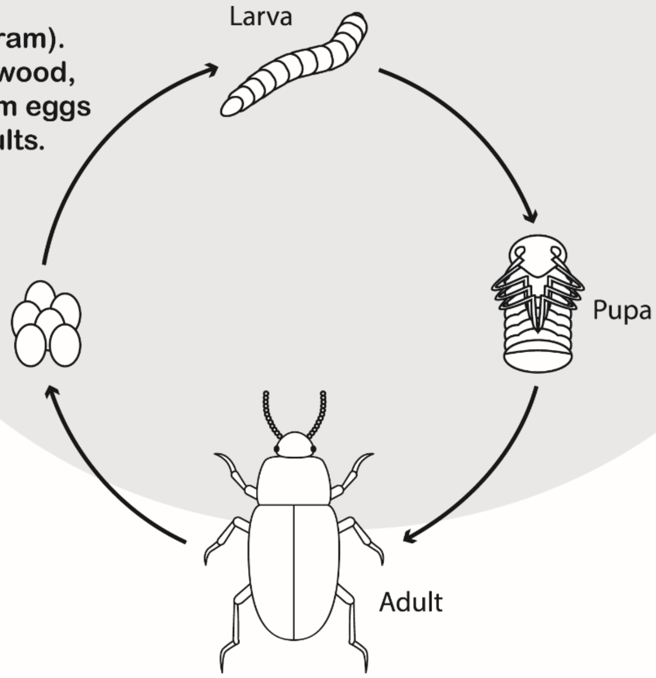
Caterpillars (*Agrius* sp.) (right) have three true legs from the thoracic (front) segments just behind the head and usually five pairs of fleshy prolegs on the third to the sixth abdominal segments, used to hang onto leaves, stems, bark, etc.

Looper caterpillars are different: they have three true legs, an anal or last pair, but fewer other pairs depending on the family. This reduction means that the caterpillars travel in 'loops' as seen in the image of (*Chrysodeixis* sp.) (left).

Fig. 2.5 Life cycle of moths and butterflies (order Lepidoptera).

Beetles and Weevils

These have complex life cycles (Diagram). Eggs are laid on or in the soil, rotten wood, even animal faeces. Larvae hatch from eggs and develop into pupae, and then adults.



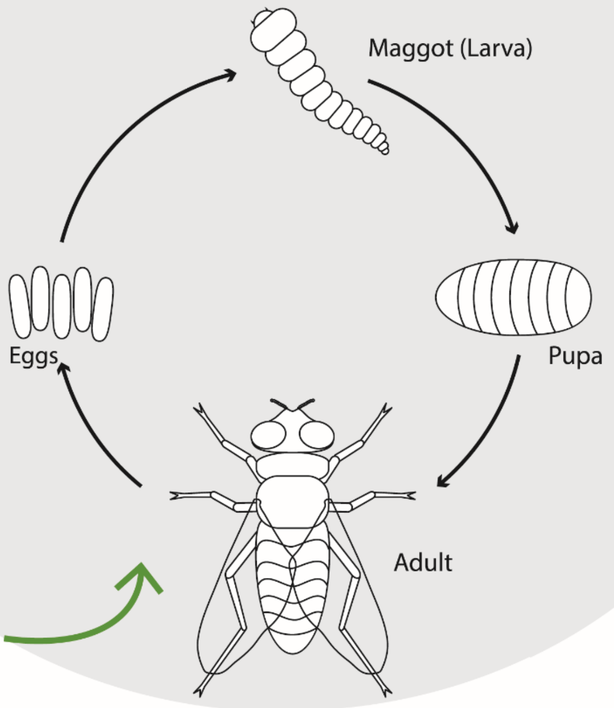
Beetles have two pairs of wings the first or front pair are hardened (the elytra) to protect the second pair which are used for flight, although not all beetles fly. Note, the wings meet in the middle of the back (unlike the 'true bugs').

Weevils are a group within beetles. They have characteristic snouts, although some are not long as in the image above.

Fig. 2.6 Life cycle of beetles and weevils (order Coleoptera).

Flies

Flies have complex life cycles (see diagram). The eggs (many species do not have eggs, but give birth to living young) hatch into legless larvae (maggots), which increase in size after successive moults. They pupate within the dried skin of the larva to form a small, walled 'puparium'. Some produce free-living pupae in water (e.g., mosquitoes) that hatch into adult flies. Adults may be useful pollinators of flowers, or fruit fly pests. Leafminers and fruit flies are common pests in the Pacific islands. Note, whiteflies are not members of this order; they are members of the aphid, leaf and planthopper, psyllid, mealybug, scale insect order (Hemiptera).



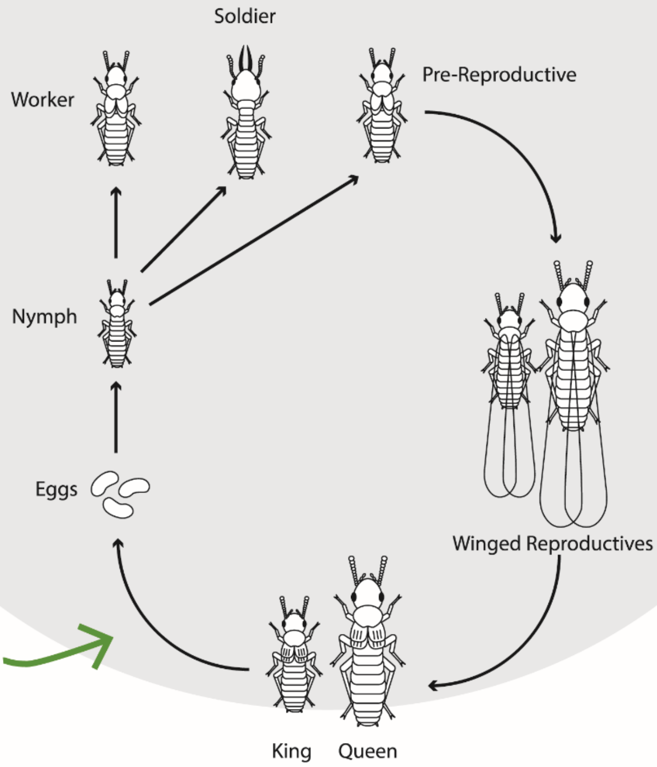
Leafminer (*Liriomyza* sp.). The adult fly is tiny and not easily seen. It is the larva (the maggot) that causes the damage as it mines the leaves. The pupa usually falls from the leaf and matures in the soil.

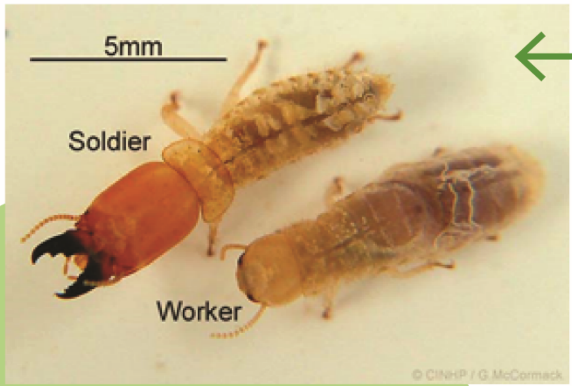
Fruit fly (*Bactrocera* sp.). Adult flies have a single pair of wings. In most cases, they lay 1-20 eggs into maturing fruits together with bacteria that provide food for maggots, either directly, or indirectly by causing fruits to rot. The fruit fall to the ground and the larvae enter the soil to pupate.

Fig. 2.7 Life cycle of flies (order Diptera).

Termites

Termites have simple life cycles. Unlike ants, termites have only egg, nymph and adult stages. They are social insects that are now placed in the cockroach order (Blattodea). Like ants, and some bees and wasps, termite colonies have sterile male and female 'workers' and 'soldiers' (see diagram). They also have fertile 'reproductives' (with two pairs of wings) – producing males called 'kings' and one or more fertile females called 'queens'. Termites mostly feed on dead plant material - wood, leaf litter, soil, or animal dung. In subtropical and tropical regions, their recycling of wood and plant matter is ecologically important. Termite colonies range from a few hundred to several million individuals.



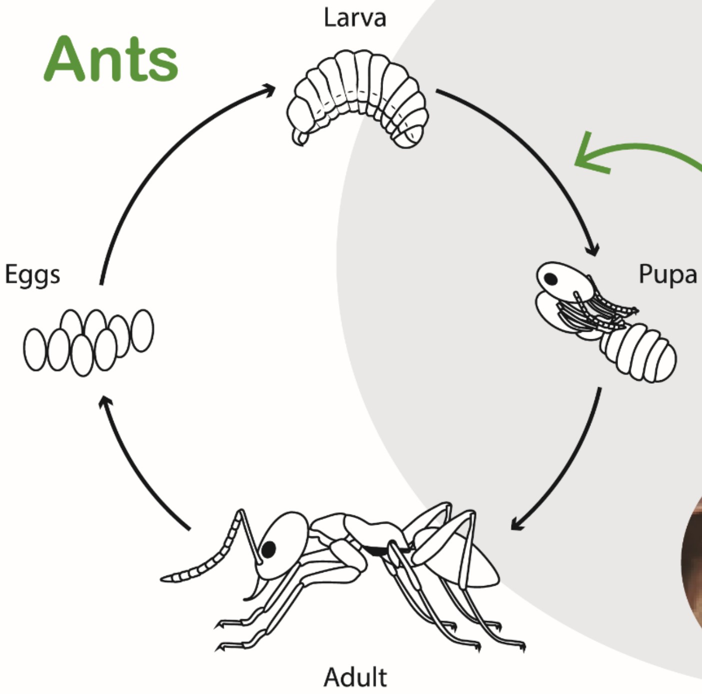


Termite (*Neotermes* sp.). The life cycle begins with the winged (they have two pairs) reproductives leaving the colony to swarm. Females and males pair, they shed their wings, look for a place to start a new colony, and mate. The female lays eggs and both sexes (king and queen) take care of the offspring until there are enough workers to take over.

Mating continues for life (unlike ants which mate only once). It may take up to 10 years before the king and queen have built a colony that produces reproductives once more.

Fig. 2.8 Life cycle of termites (order Blattodea).

Ants



Ants have complex life cycles (see diagram). The eggs hatch into legless larvae, which increase in size as they moult before becoming pupae then adults.

Oecophylla weaver ant.

Within an ant colony there are one or multiple queens, a few sexually active males (from unfertilised eggs) and large numbers of wingless female workers (from fertilised eggs) that cannot reproduce. Female workers have different tasks: caring for the eggs and larvae; gathering food; or defending the colony. Adults feed on liquid foods (hence their attraction to honeydew) and parts of seeds rich in fat and protein. They are also predators or scavengers of insects and spiders that are fed to larvae. A new colony starts when a queen lays eggs and the resulting larvae develop into new winged queens and males, and they leave the nest and mate in the air. The males die and the queen finds a new place to start a colony by laying eggs which become workers.

Weaver ants tending mealybugs on cocoa.

Fig. 2.9 Life cycle of ants (order Hymenoptera).

Bees (leafcutting)

Bees and wasps have complex life cycles much like ants (see the lifecycle diagram for ants). The eggs hatch into legless larvae, which increase in size as they moult before becoming pupae then adults.

Leafcutting bees (like this *Megachile* sp.**) are mostly solitary, occurring in countries throughout the world. They cut discs from leaves to build nests, often in rotting wood. The nest has a line of cells each with a single egg and a ball of pollen for the larva when it hatches. Adults feed on nectar and pollen, and are important pollinators of some crops, ornamentals and wildflowers. They are regarded as pests where they spoil the aesthetic look of plants and take pieces from leaves.**

Wasps

Wasps are mostly solitary, although some, such as the yellowjackets and hornets, live in colonies with queens and non-reproductive workers. Social wasps have life cycles similar to ants and bees, except the workers hunt other insects and spiders to feed their carnivorous larvae. However, there is considerable difference between social and solitary wasps. Some solitary wasps lay eggs in other insects, and are important in biological pest control. They are similar to parasites but, importantly, they kill their hosts, and are known as 'parasitoids'. All life stages - eggs, larvae, pupae or adults - of other insects (and some other arthropods) are targeted as hosts, depending on the parasitoid species. Adult parasitoid wasps mainly feed on nectar, but only a very few species are involved in pollination.

Diadegma sp.**, a wasp parasitoid, laying its egg in a larva of Diamondback moth**

Fig. 2.10 Life cycle of bees and wasps (order Hymenoptera).

Sawflies

Many species of sawflies have males, but many do not, and females produce eggs without fertilisation. Sawfly larvae often feed on leaves (sometimes de-foliating trees). They look very much like the caterpillars of moths or butterflies – they have thoracic legs and prolegs.

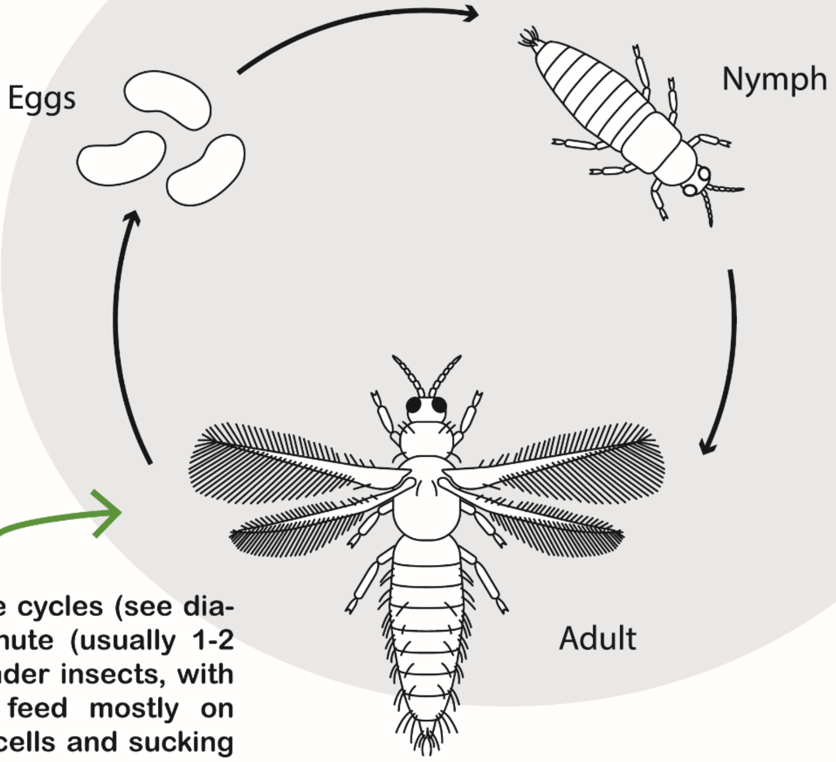
Sawfly caterpillars (*Neodipiron* sp.*)*. Note there are eight pairs of prolegs, greater than the number of pairs commonly seen on caterpillars of moths and butterflies

Adult sawfly (*Neodipiron* sp.*)*

Adults do not have a 'waist', typical of bees and wasps, and they feed on pollen, nectar and sap. Females have long ovipositors that have a saw-like appearance used for cutting into plants to lay their eggs (hence their common name). The ovipositor looks like a 'stinger'.

Fig. 2.11 Life cycle of sawflies (order Hymenoptera).

Thrips

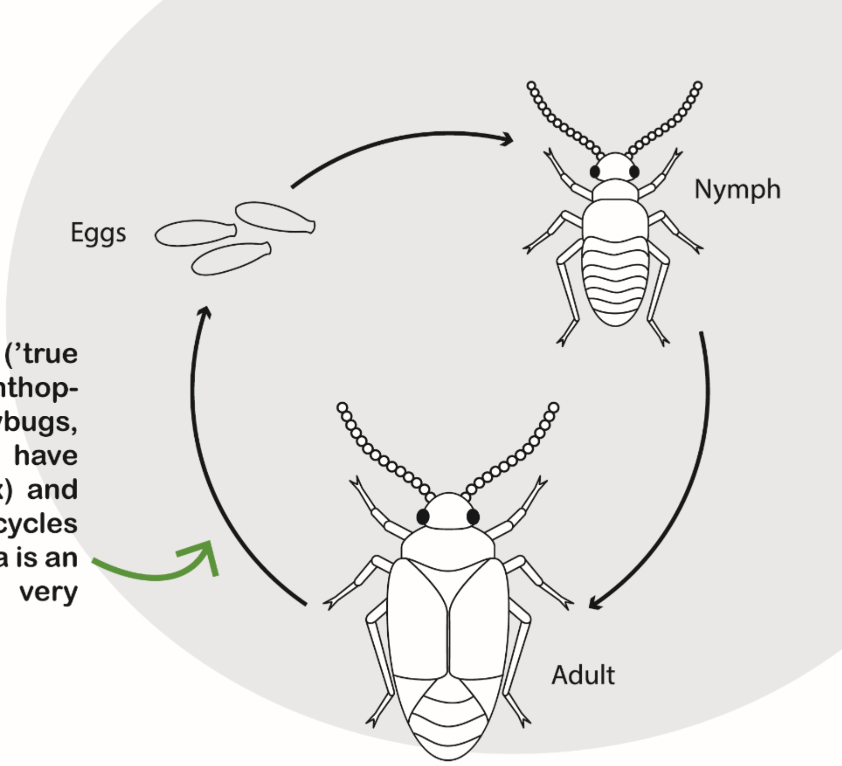


Thrips have simple life cycles (see diagram). Thrips are minute (usually 1-2 mm long or less), slender insects, with fringed wings. They feed mostly on plants by puncturing cells and sucking up the contents, although in a few cases they are predators of other thrips, other insects or mites. They are weak fliers, but are often spread on the wind. Many thrips are pests, and some, such as the tomato spotted wilt virus, cause important plant diseases. Others are beneficial pollinators.

Eggs, nymphs and adults.

Fig. 2.12 Life cycle of thrips (order Thysanoptera).

Aphids



Various aphids, bugs ('true bugs'), leafhoppers, planthoppers, psyllids, mealybugs, scales and whiteflies have both complete (complex) and incomplete (simple) life cycles (see diagram). Hemiptera is an order of insects with very diverse life cycles.

Aphids have a simple life cycle. Some species lay eggs, i.e., where they have to survive the winter in temperate or sub-tropical regions. In the tropics, females give birth to living young, without having to mate, producing more females. The young are wingless versions of adults. Colony development is rapid. Later, when colonies become crowded or the host plants begin to die, winged forms develop for dispersal.

Citrus aphids (*Taxoptera* sp.): nymphs, winged and wingless adults.

Fig. 2.13 Life cycle of aphids (order Hemiptera).

True bugs

'True bugs' are members of the sub-order Heteroptera (order: Hemiptera). They have simple life cycles: they lay eggs or give birth to living young that get larger gradually by moulting. There is no resting (pupa) stage. Adults have fully developed wings, although some species are without wings or have short wings. If present, the wings form an X-shaped pattern when folded at rest. The word heteropteran means 'different wings' as most have forewings that are part membranous and part hardened. Nymphs are generally softer and 'squishier' than adults.

An adult bean pod sucking bug (*Riptortus* sp.). Note, the X made by the folded wings when at rest. The bodies of nymphs mimic that of ants (inset)

Leafhoppers & planthoppers

Leaf and planthoppers have a simple life cycle, and are members of the sub-order Auchenorrhyncha. There are males and females. Eggs, produce nymphs, then short-winged adults; later, when crowded or food supplies are short, long-winged forms develop for dispersal. Some members of both groups spread important plant diseases.

Nymphs of a leafhopper (*Amrasca* sp.).

Planthoppers, *Tarophagus* sp., showing winged adults and nymphs at different stages of development.

Fig. 2.14 Life cycle of true bugs, leafhoppers and planthoppers (order Hemiptera).

Psyllids

Psyllids have a simple life cycle, and are members of the sub-order Sternorrhyncha. They look like miniature cicadas. Commonly called a plant louse (or plant lice for plural), or even jumping plant lice. Eggs are laid on new shoots, and nymphs go through several moults. Adults are about the size of winged aphids, but, in contrast, they have wings folded over their bodies. Nymphs and adults suck sap. Many species produce strings of wax, or waxy covers over their bodies, e.g., the citrus psyllid that spreads Huanglongbing (citrus greening) disease.

An Asian citrus psyllid (*Diaphorina citri*). The angle of the body relative to the suface the insect is resting on is characteristic of this species.

Mealybugs

Mealybugs (and scales) are closely related (sub-order Sternorrhyncha), but in different families. The soft bodies of mealybugs are covered in mealy or cottony wax with waxy threads around them. They are often found in groups and generally able to move short distances. Eggs are laid singly or in clusters (often embedded in waxy threads), and hatch to produce 'crawlers' which have legs and are quite mobile; these wander around or are spread on the wind before settling down to feed by sucking sap. They moult through several stages. In males, the last stage, called a 'pupa', produces a winged adult that looks like a tiny mosquito with one pair of wings, but without a mouth, whose function is only to mate. Note, not all species lay eggs: some give birth to living crawlers, and some other species do not have males – females are produced without fertilisation.

Adult mealybugs (*Phenacoccus* sp.): showing mealy/waxy covering and immature nymphs.

Fig. 2.15 Life cycle of psyllids and mealybugs (order Hemiptera).

Scales

Adult breadfruit scale, *Icerya seychellarum.* Presently, a huge infestation occurs in Fiji after the introduction of a white-footed ant which tends the ant protecting it from natural enemies.

Scale insects are divided into many different groups with considerable variations in their life cycles. In general, however, there are similarities with mealybugs: some lay eggs (and hatch as crawlers), some give birth to living crawlers, some reproduce without mating, and some have mosquito-like males. They are hermaphrodites, and able to self-fertilise, which is unusual in insects. As adults, the females are without legs, heads or wings. The scale of hard scales is not attached to the body, whereas it is with soft scales. In both cases, these waxy covers protect them from predators, parasitoids and pesticides. Note, hard scales do NOT produce honeydew, so they are not associated with fungal sooty moulds. Three families are illustrated below that are common scale insects of Pacific island countries: the breadfruit and cotton cushion scales (*Icerya* species) in the family Monophlebidae; armoured scale (family Diaspididae), and soft scale (family Coccidae).

Adult fluted scales (*Icerya purchasi*). They are hermaphrodites, able to self-fertilise, which is unusual in insects. The fluted part is an egg sac with many red eggs. Adults are covered in white wax.

White peach scale (*Pseudaulacaspis* sp.). Cocoons of the winged males are on the left branches; the minute, winged, males mate with females shown on the right branch. It is an armoured scale.

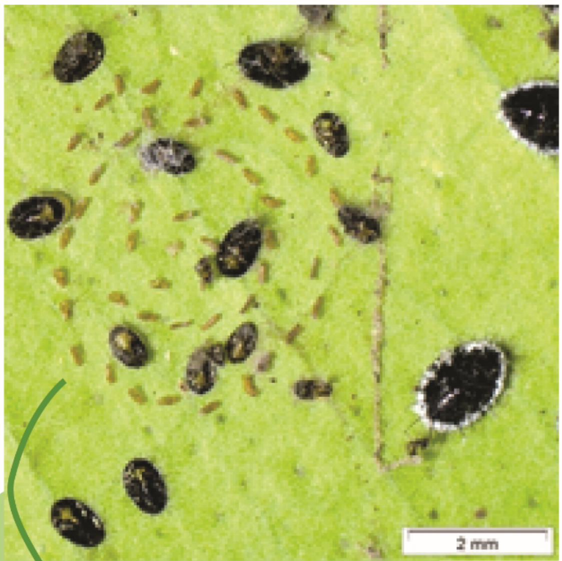
Adult Brown coffee (soft) scale (*Saissetia* sp.) Females reproduce without mating, i.e., parthenogenically, males unknown. Eggs laid under the female.

Fig. 2.16 Life cycle of scale (order Hemiptera).

Whiteflies

The life-cycle of whiteflies is similar to that of mealybugs and scales. However, there are males and females, with females being slightly larger. Eggs are laid in circular or spiral patterns on the underside of leaves. Crawlers emerge and pass through another three nymph stages. Both sexes have an intermediate pupal stage. (Note, the word 'pupa' is disputed by some authorities). Some species reproduce without mating and, in others, females mate with their offspring. The pupal stage is used for identification. Whiteflies produce honeydew which leads to sooty moulds on foliage.

Sweet potato whitefly (*Bemisia* sp.) adults and pupae with slits from which they have emerged.



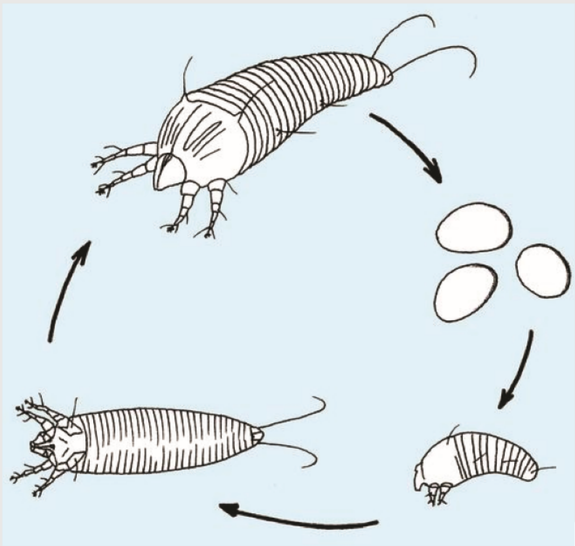
Not all whiteflies are white! Orange spiny whitefly (*Aleurocanthus* sp.) on citrus lays eggs in a spiral, produces black nymphs, and white-fringed pupae.

Pupa and adult orange spiny whitelfy

Fig. 2.17 Life cycle of whiteflies (order Hemiptera).

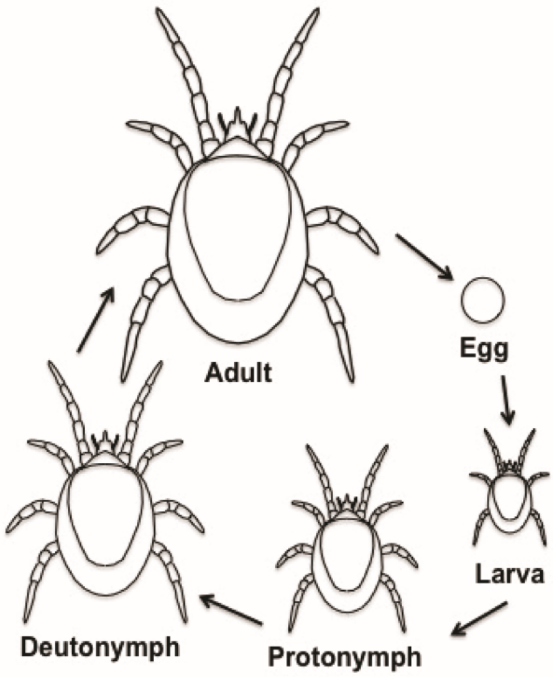
Plant mites

Tetranychid spider mites are less than 1 mm long, they lay relatively large, round, transparent eggs, and spin webs to protect themselves. Eggs hatch, producing a larvae; these moult into 1st-stage (proto) and 2nd-stage (deuto) nymphs, which then mature into adults. In hot, dry conditions populations enlarge rapidly. Eriophyid mites are smaller, and usually found living in the buds of plants, or in galls. The life cycle is relatively simple: egg, first and second nymphs, and adult.



Life cycle of an eriophyid mite.

Appearance of eriophyid (top) and tetranychid (bottom) mites.



Life cycle of a tetranychid mite.

Fig. 2.18 Life cycle of plant mites (order Trombidiformes).

2.5 Symptoms of insects and mites – what can they tell us?

Pests can be divided into those with mouthparts that chew, those that suck, and those that pierce when laying eggs (Fig. 2.19). Thrips are often said to rasp, but it is now agreed that they pierce and suck, with different mandibles (mouthparts) adapted for the tasks. See the damage they cause in Figs. 2.20-2.68.

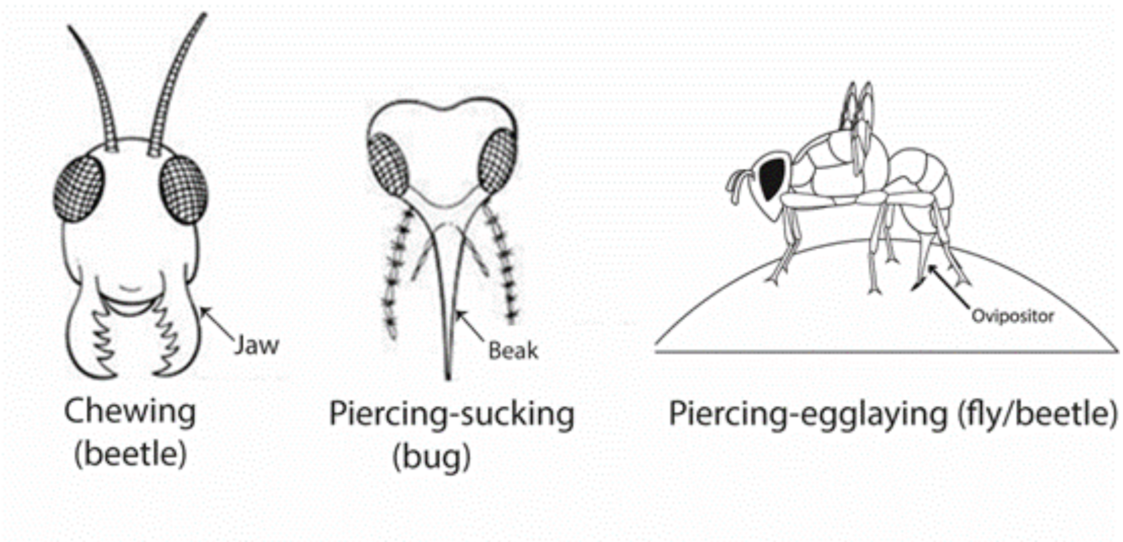


Fig. 2.19 Three ways insects cause damage on plants - chewing, sucking and piercing.

Table 2.2 describes a variety of ways that pests can damage crops, with examples and an explanation of which stages of the lifecycle are most likely to produce particular types of damage.

Table 2.2 The ways that insects damage plants, the signs of damage and the principle stage in their life cycle when the damage is done.

Mouthparts	Pests	Sign of damage	Stage of life cycle causing damage	Comments
Chewing	Grasshoppers, crickets & katydids (Orthoptera)	• Chewed leaves, flowers & stems	Adults & nymphs	
	Moths & butterflies (Lepidoptera]	• Chewed leaves, flowers & stems • Boring or tunnelling into stems and trunks	Moth & butterfly larvae (caterpillars), rarely adults (e.g., fruit-piercing moths)	
	Beetles & weevils (Coleoptera)	• Mining of leaves • Chewed leaf surface or holes through the leaf • Boring or tunnelling in bark, trunks & roots, leaving frass • Mining of leaves	Adults & grubs (larvae)	Frass is insect excrement Leaf-mining less common than Lepidoptera and Diptera
	Flies (Diptera)	• Rots in fruit • Mining of leaves	Maggots (larvae)	
	Termites (Blattodea)	• Chewed trunks & roots	Adults & nymphs	The only example in the region is the coconut termite
	Ants, bees, wasps & sawflies (Hymenoptera)	• Some bees cut out pieces of leaves • Some wasps cause galls • Ants protect aphids, scales, mealybugs from parasitoids & predators	Larvae of sawflies, adults of leaf-cutting bees & larvae of gall wasps	Ants do not damage plants directly; they protect other insects from natural enemies so they can take their honeydew. Excessive

				honeydew leads to leaves blackened by sooty mould
Sucking	Thrips (Thysanoptera)	• Scars on fruits, especially from the stalk end • Curled leaves • 'Silvering' of leaves and flowers	Adults & nymphs	'Silvering' is caused by air entering the leaf when the insect (or mite) pierces the leaf to suck the sap
	Moths & butterflies (Lepidoptera)	• Fruit-rots (round at first)	Adults (rare)	The fruit-piercing moth is an example of the adult in this group
	Aphids, bugs, leafhoppers, planthoppers, psyllids, mealybugs, scales & whiteflies (Hemiptera)	• Small spots on leaves, flowers fruits (leading to rots) & also on seeds • Sooty moulds (fungi) • Wilts, stunted foliage & dieback • Galls	Adults & nymphs	Sooty mould fungi grow on the honeydew excreted from aphids, mealybugs, planthoppers, scale & whiteflies
	Mites (Trombidiformes)	• Speckling and/or 'silvering of top surface of leaf, with mites & webbing beneath • Severe leaf distortions and/or galls	Adults & nymphs	Two types of mites: those living on leaves (tetranychids) & those in buds or galls (eriophyid)
Piercing	Flies, beetles & weevils	• Small spots or holes on fruits with bruising around • Dark liquid oozing from fruit	Adults	The damage is called a 'strike' when done by fruit fly

2.5.1 Chewing pests

Grasshoppers, crickets and katydids (Figs. 2.20-2.22)

Adults and nymphs eat large areas of leaves and soft stems, e.g., grasshopper attack on sugarcane and katydid damage to banana and oil palm. Note, leaf damage is similar to that caused by caterpillars, but there is no frass (i.e. faeces). Often, damage from grasshoppers and katydids starts from the margin of the leaf, but not always. Crickets are different in their eating habits from the other two; they are 'omnivorous', meaning they eat many different kinds of food - plants, other insects including eggs, larvae and pupae, and also the remains of dead animals.

Fig. 2.20 Damage on long bean by small (identity unknown) grasshopper that eats only patches of the leaf surface; the patches may turn into holes later as the damaged parts fall away. There is no sign of frass. Other groups of insects only eat the surface areas of leaves (Fig 2.23).

Fig. 2.21 Grasshopper (unknown) damage on sugarcane shows a solitary insect, and clearly the damage started at the edges of the leaf, where the grasshopper continues to feed. Note, lack of frass, which might otherwise suggest caterpillar damage.

Fig. 2.22 Katydid (*Sexava* sp.) on oil palm and banana can be devastating, where the entire leaf is stripped, leaving only the midrib.

Moths and butterflies (caterpillars) (Figs. 2.23-2.31)

Caterpillars chew all plant parts, but most commonly leaves. They also bore into succulent stems and fruits. In many cases, the damage they cause is diagnostic for a particular type of insect on a particular crop, e.g., cluster caterpillars on taro, but symptoms can also be similar to those of other groups. For example, moths, flies, sawflies and beetles all have larvae that produce leafmines and blotches - although in terms of numbers, moths have the greatest number of species that feed in this way. Similarly, holes in leaves are caused by caterpillars, but also by grasshoppers (nymphs and adults) and beetles (adults and larvae). Larvae of both moths and beetles also bore into stems, producing wilts and leaving frass. The following examples show the variety of damage done and, importantly, show that by comparison with other groups, the damage is not exclusive. The symptoms illustrated are: chewing surface layers of leaves, eating entire leaves, mining leaves, making holes in leaves, folding leaves, rolling leaves, and boring stems and fruits.

Fig. 2.23 Surface layers eaten by young, gregarious taro armyworm (*Spodoptera* sp.), called a taro cluster caterpillar at this stage (left). Later, solitary caterpillars eat the entire leaf, leaving only the petioles (right).

Fig. 2.24 Surface layers eaten by the coconut flat moth (*Agonoxena* sp.) from the underside of the leaf.

Fig. 2.25 Mines (blotches) made under the leaf surface by the cowpea leaf miner (*Phodoryctis* sp.). Compare this symptom with the mines made by leafminers of flies (Fig. 2.42) and beetles (Figs. 2.34-2.36).

Fig. 2.26 Holes in leaves. At first, caterpillars of diamondback moth (*Plutella* sp.) make 'windows' in the leaves of cabbages by eating the surface layers; later, the larger caterpillars eat through the leaf making holes.

Fig. 2.27 Folds and holes in leaves (*Psara sp*.). The caterpillars fold the leaves, presumably for protection, and eat holes in the leaves as they mature. The red sweet potato beetle *(Candezea)* sp.) makes similar holes in leaves, although it does not fold them.

Fig. 2.28 Rolls of leaves. The banana skipper (*Erionota* sp.) caterpillar has rolled the leaves to live and eat inside.

Fig. 2.29 In a similar way to the banana skipper, the cotton leaf roller (*Haritalodes* sp.) on *bele* has rolled the leaves, although less spectacularly.

Fig. 2.30 Wilt caused by a caterpillar (*Erias* sp.) boring into a stem, *bele* (left). Internal boring of *bele* stems, rot, caterpillar and frass (right).

Fig. 2.31 Bored fruit. A common symptom of capsicum caused by the caterpillar of the corn earworm (*Helicoverpa* sp.). It also attacks fruit of tomato and eggplant.

Beetles and weevils (Figs 2.32-2.42)

Symptoms caused by beetles and weevils vary, and some are similar to those made by caterpillars of moths and butterflies. Adults in or on leaves may make straight lines, wavy lines, circles from stripping surface tissues on one side of leaves, holes through leaves, and holes into stems and trunks. Some larvae (called 'grubs') mine leaves. Weevils – a large sub-group of beetles, some with long snouts – attack fruits, leaves, trunks, roots and stored products, as well as causing many other symptoms similar to those of beetles. Many weevils are also biocontrol agents of weeds and therefore beneficial to human beings.

Fig. 2.32 Feeding grooves cut parallel to the veins of ginger caused by unknown beetle (left). Feeding grooves cut into sweet potato leaves by flea beetles (*Chaetocnema* sp.) stripping the surface and making wavy lines (right).

Fig. 2.33 Outer layers of the cucumber leaf stripped away by a phytophagous ('plant-eating') 28-spot ladybird beetle (*Epilachna* sp.). The adults and larvae have 'skeletonised' the leaf in patches.

Fig. 2.34 Mines (blotches) made by the larvae of the coconut leafminer (*Promecotheca* sp.), a beetle.

Fig. 2.35 Small holes in *bele* caused by a flea beetle (*Nisotra* species).

Fig. 2.36 Holes in cucumber cut by the pumpkin beetle *(Aulacophora* sp.). It is thought that the beetle cuts out leaf circles in order to reduce toxic substances from entering them.

Fig. 2.37 Boring in oil palm fronds by the coconut rhinoceros beetle (*Oryctes* sp.). Similar holes are bored through the base of coconut fronds.

Fig. 2.38 Boring by larva (grub) of the cocoa weevil borer (*Pantorhytes* sp.). Gum is often produced by the tree in response to the presence of the larva, and there may be frass at the opening of the hole.

Fig. 2.39 Wilt of *Amaranthus* caused by a stem weevil (*Hypolixus* sp.). A symptom similar to that of *bele* (Fig. 2.30 left). Several larvae bore into the stem eating the interior and filling it with frass. Cankers form on stems and branches as fungi take advantage of the damaged plants.

Fig. 2.40 Boring into the corm of taro by adult taro beetle (*Papuana* sp.)

Fig. 2.41 Boring into storage roots by larvae of sweet potato weevil (*Cylas* species).

Fig. 2.42 Bored grain in storage damaged by the lesser grain weevil (*Sitophilus* sp.). Both adults and larvae do the damage, by feeding inside the grains.

Flies (Fig. 2.43)

Leaf-mining fly maggots burrow just beneath the outer leaf layers similar to leaf-mining caterpillars. Note that larvae of leaf mining moths deposit frass down the middle of the mine, whereas leaf-mining fly maggots tend to leave the frass alternating between the sides of the mine. The reason for these alternating deposits of flies is the larva feeds on its side, and from time to time rolls over. Larvae of moths (and beetles and sawflies) feed either belly-up or belly-down, and frass is deposited down the middle of the mine[8].

Fig. 2.43 Mines made by the larva (maggot) of a fly leafminer (*Liriomyza* sp.) on tomato. The mines are very similar to those made by larvae (caterpillars) of moths.

Termites (Figs. 2.44-2.45)

Crop damage by termites is unusual in Pacific islands, although damage to buildings is common. Serious damage on coconuts does occur, but this appears to be confined to atoll countries. If symptoms are seen similar to those of Fig. 2.44, they should be reported immediately to agricultural authorities. The presence of the coconut termite in Rotuma (Fiji) is thought unlikely, but another species is damaging both coconut and citrus.

Fig. 2.44 It is not common for termites in the region to attack living plants or trees, but there are exceptions. The coconut termite (*Neotermes* sp.) attacks living palms in some atoll countries. It makes grooves into the bark for reasons unknown, but their appearance is considered diagnostic for the species.

Fig. 2.45 Surface termite tunnels and a nest in the trunk of a living coconut (Rotuma, Fiji). An unknown termite species is attacking coconuts and citrus on the island.

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[8] Eiseman, C. (2020). Leafminers of North America. 2nd Edition. (http://charleyeiseman.com/leafminers/).

Ants, bees, wasps and sawflies (Figs. 2.46-2.48)

Within this group there are relatively few examples of damage caused directly by chewing adults or larvae. There are leaf-cutting bees that spoil ornamental flowers, gall wasps, e.g., *Quadrastichus* larvae on *Erythrina* trees, and sawflies that occasionally strip leaves.

Fig. 2.46 Leaf cutting bee (*Megachile sp.).* The adult causes the symptoms. The bees live in burrows; they make cells from the leaf pieces, place eggs and pollen inside for the young and then seal the cell.

Fig. 2.47 Sawfly larvae (*Nematus sp*.) are similar to moth caterpillars except for a greater number of prolegs. The damage by sawflies and caterpillars can be similar.

However, for the most part, bees and wasps are considered beneficial and important, wasps especially so, as they are parasitoids, natural enemies of plant pests. Where problems exist they are of different kinds. Introduced Asian bees compete with honey bees, and wasps (and hornets) may be a nuisance as they sting humans and animals.

Fig. 2.48 Galls produced by the larvae of the *Erythrina* gall wasp (*Quadrastichus* sp.). The larvae feed on the leaves and the tree responds by producing swollen deformed leaf galls. Note, insects of many orders as well as mites, produce galls.

Invasive ants especially are a major problem in Pacific islands, some out-compete native species, seriously disrupting ecosystems. Further, they feed on honeydew from scale insects, mealybugs, aphids, psyllids and planthoppers, protecting them from their natural enemies. Plants are weakened as honeydew supports mould fungi which blacken leaves, restricting photosynthesis. See also Section 2.5.2 on aphids and related insects under sucking insects.

2.5.2 Sucking pests

Thrips (Figs. 2.49-2.51)

Silvering on fruits and leaves is a common symptom on plants in Pacific island countries; this is seen commonly on capsicum, onion, mango and eggplant. On capsicum and eggplant, thrips enter the fruit buds when they are very young. Symptoms also occur on the flowers of some plants.

Most thrips feed by puncturing plant cells and sucking up the contents. The damage is done early, but becomes noticeable only later when the leaves and fruits expand: they become discoloured, silvery, and distorted. Some thrips are beneficial predators.

Symptoms of thrips are similar to those caused by spider mites. However, often the thrips have disappeared by the time that the leaves and fruits emerge. In some species, populations of thrips can be found within the folded, rolled leaves (e.g., *Ficus*) or on the underside of leaves (e.g., taro). Note, some species of thrips spread viruses.

Fig. 2.49 Thrips on shallot (*Thrips tabaci*) Thrips have unusual mouth parts: one side cuts or hammers the leaf surface to rupture the cells, while the other part has a tube to suck up the contents.

Figure 2.50 Thrips sp. silvering of leaves is a typical symptom of thrips.

Fig. 2.51 *Thrips* sp. scarring on fruit of capsicum (left) and eggplant (right). On both, the thrips have entered the bud at an early stage, fed on the fruit as it developed, creating the 'dragged-out' symptom as the fruit expanded (especially noticeable on eggplant). By this stage, the thrips have moved to younger fruit.

Moths and butterflies (Fig. 2.52)

Sucking damage by moths and butterflies is rare. The one important example in Pacific island countries is the fruit-piercing moth, a pest of citrus and many vegetables, especially tomato. The caterpillars develop on *Erythrina* trees.

Fig. 2.52 Fruit piercing moth (*Eudocima* sp.) on orange. The moth has sucked juice from the fruit and secondary invasion by rotting-causing organisms has caused the fruit to drop.

Aphids, true bugs, leafhoppers, planthoppers, psyllids, mealybugs, scale insects and whiteflies (Figs. 2.53-2.63)

All these groups suck sap to feed, and symptoms vary. Aphids, leaf and planthoppers, and psyllids cause distortions and wilting; true bugs cause spotting and stem cankers; and mealybugs and scales can cause leaf distortion and dieback. Many produce honeydew (aphids, leaf and planthoppers, mealybugs, soft scales, whiteflies), which promotes sooty moulds which reduce photosynthesis, stunt growth and cause early leaf fall. Ants tend these insects for their honeydew and protect them from natural enemies. Aphids, psyllids, leaf and planthoppers, mealybugs and whiteflies spread pathogenic bacteria and viruses.

Fig. 2.53 Distorted young leaves of basil caused by aphids (*Aphis* sp.) feeding on the underside. Mealybugs can produce similar symptoms on other plants (Fig. 2.54).

Fig. 2.54 Distorted young leaves of tomato caused by mealybugs (species unknown) on plants grown under protected cropping. The white fluffy waxy growth often covers eggs and young stages and is typical of mealybug infestations.

Fig. 2.55 Spotting on fruits by the feeding of the fruit spotting bug (*Amblypelta* sp). A related species causes premature nut fall of coconuts, and dieback of cassava (Figs. 2.56 & 2.57).

Fig. 2.56 Cankers on stem of cassava from 'true' bug (*Amblypelta* sp.) feeding. The scars on the stem have been invaded by a (secondary) fungus - notice the fruiting bodies - which assist in the development of the cankers.

Fig 2.57 Feeding by *Amplypelta* results in leaf wilt, dieback, and cankers on the stem.

Fig. 2.58 Wilt of rice due to planthopper attack (*Nilaparvata* sp.). Large numbers cause 'hopper-burn' as the plants become dehydrated, wilt and collapse. This is a common symptom in rice when pesticides are used and natural enemies are destroyed, and the planthoppers increase in number as a result.

Fig. 2.59 Psyllid galls on Malay apple, common in Pacific island countries, caused by the Malay apple gall psyllid (*Trioza* sp.). Eggs are laid on the underside of the leaf and the nymphs enter the leaf, stimulating the leaf to develop galls on the upper surface.

Fig. 2.60 Sooty mould, an indirect result from soft scale infestations *(Ceroplastes* sp.). The scale produces 'honeydew', a waste liquid from feeding on plant sap which falls onto the foliage and is colonised by fungi, resulting in characteristic black growth.

Fig. 2.61 Ants (*Technomyrmex* sp.) tend scale insects for their honeydew, and in the process protect them from their natural enemies, allowing large infestations to occur. This has happened in Fiji with the introduction of the white-footed ant.

Fig. 2.62 Lesser snow scale (*Pinnaspis* sp.), an armoured scale on oil palm fruit. The female scale can be seen as pale brown round objects on the fruits in the centre; the white areas are the cocoons of the male scale.

Fig. 2.63 Spirals and adults of the spiralling whitefly (*Aleurodicus* sp.). Eggs are laid in the waxy spirals.

Mites (Figs. 2.64-2.66)

There are two types of mites that are common pests in Pacific island countries. One is represented by the two-spotted mite, that causes white/greyish speckling on the top of leaves and webbing on the underside. The other is represented by the much smaller broad mite that lives inside buds and causes yellow patches and distortions on leaves and fruits. It is common on capsicum and tomato. A hand lens or microscope is useful to see mites.

Fig. 2.64 Speckling symptom on taro caused by the feeding of two-spotted mites (*Tetranychus* sp.), most often on the under surface of leaves. The silvering is said to be caused by air entering cells punctured by the mites as they feed.

Fig. 2.65 Distortions on capsicum, commonly caused by broad mite (*Polyphagotarsonemus* sp). Symptoms can be mistaken for distortions caused by virus infection.

Fig. 2.66 Galls formed by the sweet potato gall mite. This is caused by an eriothyid mite (*Eriophyes* species).

2.5.3 Piercing pests

Flies (Figs. 2.67 & 2.68)

Some insects pierce fruits when laying eggs. In Pacific island countries, fruit flies are a common example of this. At the same time as they insert eggs, they inject bacteria that cause rots and provide food for the maggots. Weevils also lay eggs in fruit.

Fig. 2.67 Eggs laid by the mango seed weevil *(Sternochetus* sp.*)* cause sap to be released which dribbles down the fruit before hardening.

Fig. 2.68 'Strikes' on tomatoes where fruit has been pierced by fruit flies (*Bactrocera* sp.) in the process of laying eggs.

2.5.4 Similar symptoms, different groups

It is not surprising that different groups of pests may cause similar symptoms, as they have only two methods of feeding on plants (chewing and sucking) and one method of laying eggs (piercing). For instance, among the chewing insects it can be hard to tell whether the damage was done by an adult chewing beetle, an adult (or nymph) katydid or a leaf-cutting bee (Table 2.3). All have mandibles, which are hardened and tooth-like for cutting and crushing.

When it comes to sucking insects and mites, again buds, leaves and stems are damaged, but the symptoms differ from those caused by chewing insects. Again, this should not surprise us as the method of feeding is quite different - sucking insects tap into vascular systems for liquid food. This kind of feeding causes distortions, galls, stippling/silvering, wilting, and dieback.

In only two cases do we see different groups causing similar damage. Galls are produced by some aphids, psyllids, thrips and broad mites, and speckling/silvering can be caused by thrips, true bugs, and both kinds of mites (Table 2.3). Of interest though, is that within the large grouping, order Hemiptera, similar symptoms are produced by insects that appear quite different, but this is understandable, considering their common underlying biology.

From a plant health doctor standpoint, all this information can be quite confusing, but it is provided here as a warning to doctors not to assume that a particular symptom can always be interpreted as the result of the feeding of a particular kind of insect or mite. A smart plant health doctor, when given a sample with symptoms but without any likely cause, will always have questions to ask! Table 2.3 summarises the similar symptoms caused by different orders of pest.

Table 2.3 Similar symptoms but different orders: examples from the Pacific Pests, Pathogens & Weed app.

Plant part attacked/ Symptoms	Order (common name)	Stage causing damage	Insect or mite (examples)	Crop (example)	Fact sheet #
TYPE OF DAMAGE: CHEWING					
Leaf, make holes, or stripping					
	Coleoptera (beetle)	Adult	*Candezea*	Sweet potato	53
	Lepidoptera (moth)	Larva	*Plutella*	Cabbage	20
	Orthoptera (katydid)	Adult, nymph	*Sexava*	Oil palm	246
	Hymenoptera (bee)	Adult	*Megachile*	Ornamentals	N/A
Leaf, mining (serpentine or blotch)					
	Coleoptera (beetle)	Larva	*Promecotheca*	Coconut	60
	Diptera (fly)	Larva	*Liriomyza*	Tomato	110
	Lepidoptera (moth)	Larva	*Phodoryctis*	Cowpea	378
	Hymenoptera (sawfly)	Larva	*Phylacteophaga*	Eucalyptus	N/A
Leaf, scraping top layer					
	Coleoptera (beetle)	Adult, larva	*Epilachna*	Eggplant	58
	Lepidoptera (moth)	Larva	*Spodoptera*	Taro	31
	Orthoptera (grasshopper)	Adult, nymph	*Aiolopus*	N/A	N/A
Stem/trunk, boring					
	Coleoptera (weevil)	Larva	*Pantorhytes*	Cocoa	61
	Coleoptera (beetle)	Adult	*Oryctes*	Coconut	108
	Diptera (fly)	Lava	*Ophiomyia*	Cowpea	291
	Isoptera (termite)	Adult	*Neotermes*	Coconut	116
	Lepidoptera (moth)	Larva	*Earias*	*Bele*	23
Fruit, boring					
	Coleoptera (weevil)	Larva	*Cryptorhynchus*	Mango	437
	Lepidoptera (moth)	Larva	*Deanolis*	Mango	281
Seed, boring					
	Coleoptera (weevil)	Adult, larva	*Sitophilus*	Rice	338
	Lepidoptera (moth)	Larva	*Sitotroga*	Rice	337
Tuber/corm/storage root, boring					
	Coleoptera (weevil)	Larva	*Cylas*	Sweet potato	29
	Coleoptera (beetle)	Adult	*Papuana*	Taro	30
	Lepidoptera (moth)	Larva	*Phthorimaea*	Potato	298
TYPE OF DAMAGE: SUCKING					
Leaf, sooty mould					
	Hemiptera (aphid)	Adult, nymph	*Rhopalosiphum*	Maize	330
	Hemiptera (leafhopper)	Adult, nymph	*Idioscopus*	Mango	263
	Hemiptera (scale)	Adult, nymph	*Ceroplastes*	Gardenia	271
	Hemiptera (psyllid)	Adult, nymph	*Diaphorina*	Citrus	185
	Hemiptera (whitefly)	Adult, nymph	*Aleurocanthus*	Citrus	244
Leaf, distortions					
	Hemiptera (aphid)	Adult, nymph	*Aphis*	Basil	38
	Hemiptera (scale)	Adult, nymph	*Aspidiotus*	Coconut	104
	Hemiptera (mealybug)	Adult, nymph	*Phenacoccus*	Tomato	373
Leaf, galls					
	Hemiptera (aphid)	Adults, nymph	*Eriosoma*	Apple	N/A
	Hemiptera (psyllid)	Nymph	*Trioza*	Malay apple	366

	Trombidiformes (broad mite)	Adult, nymph	*Eriophyes*	Sweet potato	138
	Thysanoptera (thrips)	Adult, nymph	*Gynaikothrips*	Acacia	N/A
Leaf/fruit, speckling					
	Thysanoptera (thrips)	Adult, nymph	*Thrips*	Capsicum	49
	Hemiptera (true bug)	Adult, nymph	*Corythucha*	Eggplant	253
	Trombidiformes (Eriophyid)	Adult, nymph	*Phyllocoptrata*	Citrus	344
	Trombidiformes (2-spotted)	Adult, nymph	*Tetranychus*	Taro	24
Leaf, wilt, dieback					
	Hemiptera (true bug)	Adult, nymph	*Amblypelta*	Cassava	19
	Hemiptera (scale)	Adult, nymph	*Icerya*	Citrus	343
	Hemiptera (planthopper)	Adult, nymph	*Tarophagus*	Taro	41
	Hemiptera (mealybug)	Adults, nymph	*Phenacoccus*	Cassava	329
TYPE OF DAMAGE: PIERCING					
Fruit, egg laying (strike)					
	Coleoptera (weevil)	Larva	*Cryptorhynchus*	Mango	437
	Diptera (fly)	Larva	*Bactrocera*	Tomato	425

N/A - there are no examples in the Pacific Pests, Pathogens & Weeds app.

EXERCISE 3: Similar symptoms, different groups

Table 2.3 shows that pest symptoms can be confusing as similar symptoms can be caused by very different types of pests. Exercises 3 and 4 will help your trainees to think about symptoms of pest damage and the range of possible causes. This is a challenging exercise, but the purpose is for your trainees to recognise that similar symptoms can have may causes. It is not necessary for them to learn the names of every pest.

By thinking about and discussing the possible answers in their groups and then with the whole class, your trainees will have a deeper understanding of the complexity of pest diagnosis, so they do not immediately jump to one answer when they see symptoms.

In pairs or threes, ask your trainees to draw and complete the table below by filling in the blank cells. They will need access to the Pacific Pests, Pathogens & Weeds app facts sheets. Then ask them to compare their answers with another group and make changes if they need to. Also, they should check their answers with Table 2.3.

Discuss their answers with the whole class, especially paying attention to symptoms that are confusing.

An example is given in the first row.

Symptom	Damage type	Possible causes (pest orders – common names)	Life stage of pest	Confirmed by fact sheet #
Stem/bark boring	*Chewing*	*1. Fly* *2. Moth/butterfly*	*Larva (maggot)* *Larva (caterpillar)*	*291 & 23*
Leaf speckling				
Leaf mining				
Sooty mould				
Leaf galls				
Seed boring				
Wilt				
Leaf sooty mould				
Leaf distortions				
Leaf scraping				
Fruit strike				

*chewing, sucking or piercing

EXERCISE 4: Understanding chewing, sucking and piercing damage

For this exercise, try to find samples of leaves, fruit or roots that show symptoms of chewing, sucking or piercing, but with no visible pests. Give each pair or group of trainees a different sample of pest damage (or a photograph if you cannot find field samples). Your trainees should examine their sample carefully with a hand lens and answer the following questions. Then they should share their answers with the whole class and discuss the diagnosis process.

Plant part (leaf, fruit, root):

1. Describe the symptoms.

2. Are the symptoms typical of i) chewing, ii) sucking or iii) piecing? Explain your answer.

3. List all possible causes of these symptoms, including the life cycle stage of the pest.

4. What further information would you need to find out the actual cause?

2.6 What is a disease?

Plant diseases are caused by fungi, bacteria, nematodes, viruses, viroids and phytoplasmas. Together they are known as **pathogens.** The causes of many diseases are difficult to identify, as the pathogens are mostly hidden inside the leaves, stems, seeds, roots or soil.

Sometimes, damage caused by pests and diseases looks similar, e.g. virus and mite damage, but this is rare.

More commonly, viruses are spread by insects, sucking ones in particular, so if you suspect a virus, look for an insect too!

Fungi

Fungi (singular, fungus), vary in size from single cells to masses of thin, branched, cottony growth (called hyphae). A single strand is called a hypha (plural, hyphae), and a mass of hyphae a mycelium. Fungi feed on dead organic material or on living organisms by releasing enzymes which break down the food they are growing on into chemicals that they can absorb. Unlike plants, they are without chlorophyll so do not carry out photosynthesis, and their cell walls are of chitin (the exoskeleton of arthropods – insects, spiders and crustaceans) not cellulose, which is used by plants. They reproduce by spores, either asexually (without mating) or sexually. Spread occurs in wind and rain, on and in seeds and in other propagation materials, often associated with the domestic and international trade in plants.

Oomycetes

Oomycetes (singular, oomycete**)** were once thought to be fungi; now they are classified with algae. They are known as 'water moulds' as they like high humidity and wet soils. Differences from fungi include the fact that their cell walls are made of cellulose not chitin; the branching cottony growth (filaments) do not have cross walls; and they produce asexual spores (sporangia), each of which releases tiny spores (zoospores) with two whip-like hairs (flagella). Like fungi, sexual spores are produced, and methods of spread and survival are also similar. Many are important pathogens, including the following groups: i) *Phytophthora* species; ii) *Pythium* species; iii) downy mildews; and iv) white blister rusts. There are examples of these in the Pacific Pests, Pathogens & Weeds app.

Bacteria

Bacteria (singular, bacterium), are microscopic, single-celled organisms, found in all environments on Earth. They range in shape from spheres to rods to spirals, have a rigid cell wall, a single, circular chromosome of DNA, and some have flagella, whose whip-like actions provide movement. Nutrition is by photosynthesis or by breaking down chemical compounds using enzymes. Reproduction is by binary fission: the cell DNA duplicates, the cell content increases and the cell splits in two. Bacterial root infections can sometimes be identified by putting a cut root into water. Milky streams of bacteria may be seen streaming from the root.

Viruses

Viruses (singular, virus) are single-celled microscopic parasites of many different shapes and sizes, with a core of DNA or RNA surrounded by a protein coat or shell (called a "capsid"). They are mostly much smaller than bacteria. They need cells of other organisms for reproduction, and that is why many scientists say they are not living. They have been on the earth for billions of years, and are found in all other organisms, including bacteria and fungi. Viruses are important in transferring genes between species, so-called 'horizontal genetic transfer', which is important in the evolution of species.

Viroids

Viroids (singular, viroid) are the smallest pathogens known, and are simpler than viruses. They consist of a piece of circular RNA without a protein coat or shell. They can only reproduce within a host cell and are only found in plants, where they may cause diseases. Like viruses, viroids are thought to be non-living by many scientists.

Phytoplasmas

Phytoplasmas (singular, phytoplasma). The previous name was mycoplasma-like organism. They are similar to bacteria but do not have a cell wall, and because of that their shapes vary. They occur in the phloem of plants and are spread by sap-sucking insects, mostly leafhoppers. A little-leaf or witches' broom symptom is common, with small yellow leaves on bushy shoots. Flowers may become leaf-like. They are usually detected by electron microscopy or by molecular methods.

Nematodes

Nematodes (singular, nematode) are tiny worms that live in the soil. Males mate with females which produce eggs and the young, called 'juveniles', moult several times before becoming adult. Most are free-living, feeding on bacteria, fungi and protozoans (single-cell organisms).

Some are plant parasites and have a spear in their mouth used to enter and move through plants. Commonly, they damage root tips, causing excessive root branching or galls.

Here are five important facts about pathogens, that will help you to understand them.

1. Most pathogens are small

Of all the pathogens, only fungi can be seen with the naked eye, and then only those that produce masses of cottony growth, or the large fruiting bodies we call mushrooms, toadstools or brackets. However, when the length of all the cottony growth of some soil fungi is measured, they may not be so small - some are thought to be the largest organisms in the world as their growth extends over many hectares.

The spores of fungi are also small, and a microscope is needed to see them.

A microscope is also needed to see nematodes, and especially the plant pathogens. Fig. 2.69 shows the relative size of various pathogens compared with humans.

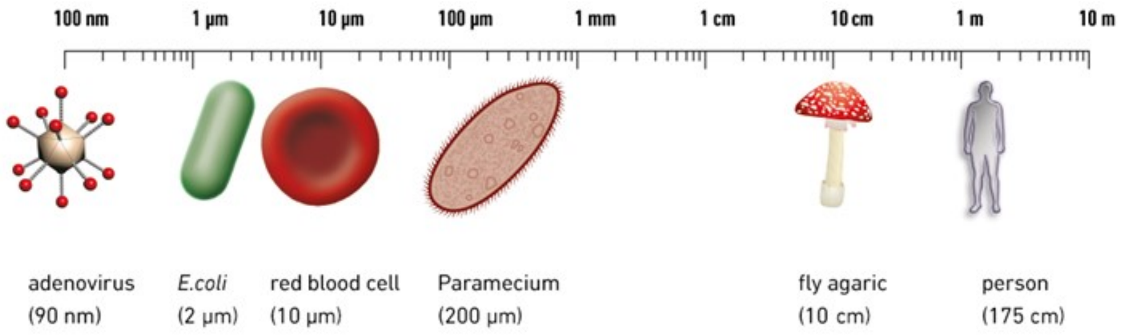

Fig. 2.69 The relative size of various pathogens compared with humans (1 µm is a millionth of a metre).

2. Pathogens reproduce very quickly

Fungi make spores of many shapes and sizes in open or closed structures (Figs. 2.70-2.71). Bacteria make copies of their DNA and then split into two. If conditions were right, it is estimated that starting with one bacterium that divides after 30 minutes, and the progeny maintain this rate of division over every generation, it would take only 48 hours to cover the world! Viruses enter plant cells and direct the cell to make their components, which are assembled into new viruses and released (Figs. 2.72-2.73).

Fig. 2.70 Fungal spores are produced in sacs through which they emerge during times of rain.

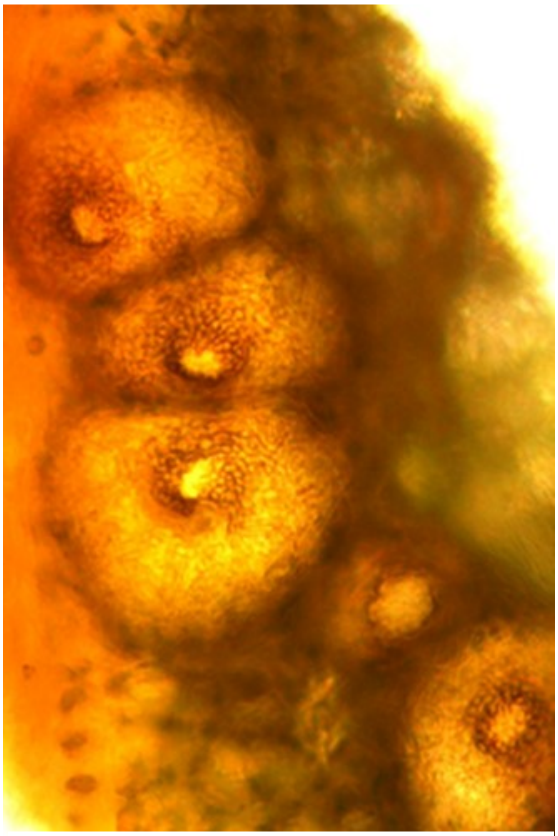

Fig. 2.71 A close-up of the sacs is shown from a similar fungus to that in Fig. 2.70.

Fig. 2.72 Fungal spores are produced on the underside of the tomato leaflets.

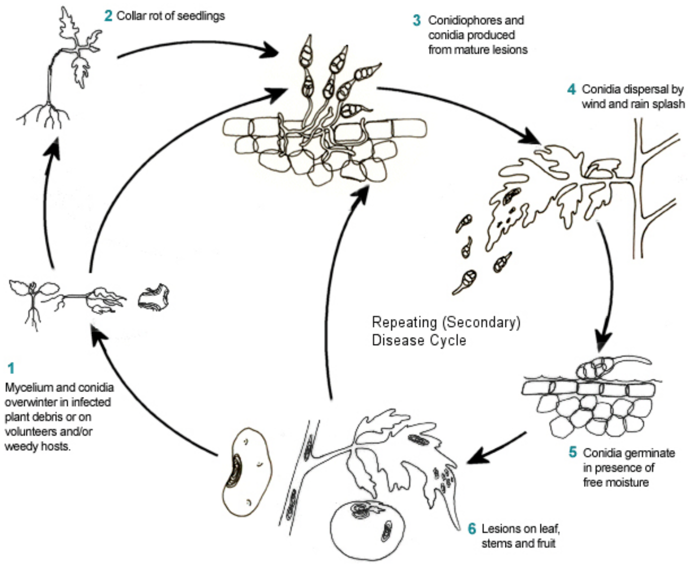

Fig. 2.73 This diagram shows how fungus emerges through the plant leaf to produce spores. In contrast to Figs. 2.70 and 2.71, the spores are not enclosed in sacs.

Plant parasitic nematodes have a spear in the mouth to damage cells of roots (Fig. 2.74) and to feed on them. In some cases, they produce chemicals that stimulate plants to make galls.

Nematodes reproduce rapidly, too. Most lay eggs that pass through immature stages (the juveniles) before becoming adult. Life cycles can be as rapid as 3-7 days, depending on the soil conditions. They have a hollow needle-like spear (called a stylet) in the mouth and this is used to puncture cells to extract food (Fig. 2.74). Some nematodes produce chemicals that stimulate plants to make galls (e.g., root knot nematodes).

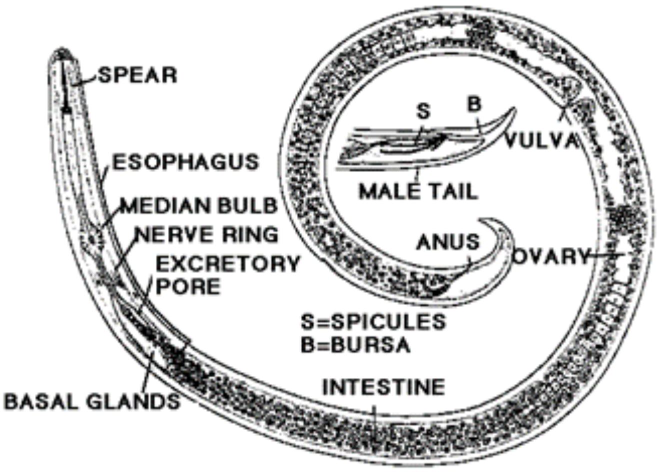

Fig. 2.74 Diagram to show the spear in the mouth of a nematode. Note that these minute organisms, mostly smaller than the naked eye can see, have a complex structure, with intestine, male and female reproductive and nervous systems.

3. Fungi and bacteria need water for infection

Fungal spores need water for germination and infection, either above or below ground. Germination produces a germ tube that penetrates either directly or through natural openings (mostly stomata), taking a few hours to do so (Figs 2.72 and 2.73). Powdery mildews are an exception: they do not need free water, but they do need high humidity. Most powdery mildews grow over the surfaces of plants, putting down short tubes to draw out nutrients. Bacteria enter through natural openings, assisted by wind-driven rain. In the soil, wounds made by nematodes or fungi assist them. Occasionally, bacteria are injected into plants by insects as they feed, in the same way that plants are infected by viruses.

4. Pathogens have many ways of spreading

A majority of fungi, oomycetes and bacteria are spread above ground in rain-driven wind (Fig. 2.75). For the most part their spores or cells are delicate and cannot withstand dehydration. There are instances where wind is the main agent of spread. There is also involvement of insects in the spread of these groups above ground, but this is less common.

Below ground, too, water plays a role, with movement of fungal and oomycete spores and bacterial cells in ground water, which also spreads nematodes. In some oomycetes, there are mobile spores (Fig. 2.76).

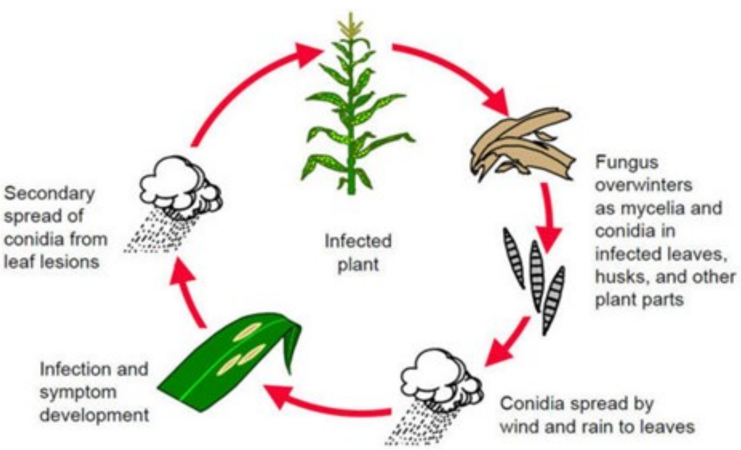

Fig. 2.75 In this fungal disease of maize, spores called 'conidia' are spread by wind and rain. In the soil, the situation is different: some pathogens, for instance, fungi, oomycetes, bacteria and nematodes, move (or are moved in water).

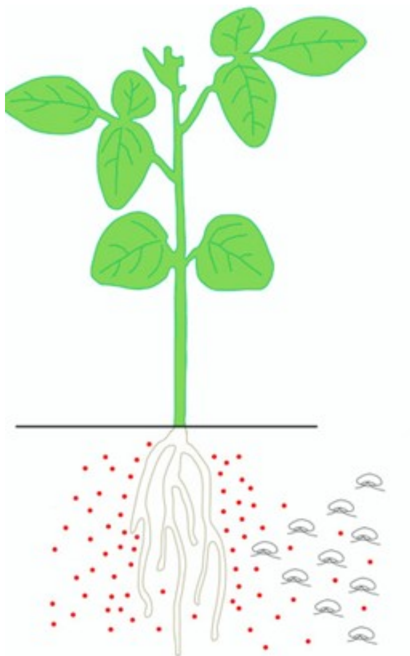

Fig. 2.76 Pathogens that have the ability to self-propel in the soil water are attracted by chemicals from the roots of plants.

Although insects play a minor role overall in the spread of fungi, bacteria and nematodes, this is not the case for viruses. Here, they are the main agent of spread. To be successful, a virus needs assistance to break through the cellulose wall of plant cells, and do it in such a way that the cells remain alive, in order to manufacture more virus. In the act of feeding by piercing and sucking, or less often by chewing, on succulent leaves and stems, insects place viruses where they need to be (Fig. 2.77).

Insects are not the only organisms that transfer viruses in this way: fungi also do it and so do nematodes, but the number of examples is very small.

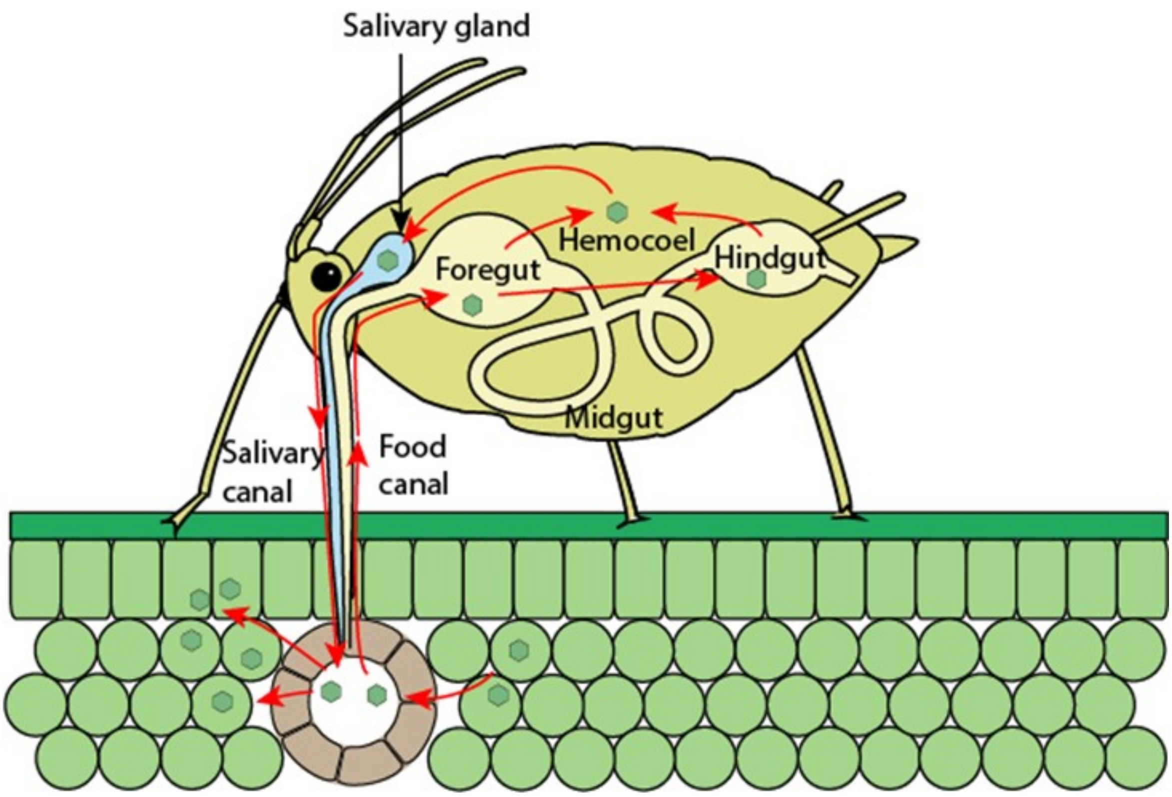

Fig. 2.77 Aphids and many other sap-sucking insects infect plants with viruses as they feed. The viruses may be i) attached to the stylets and quickly transferred or ii) passed out through the stylets after a lengthy period of multiplication within the insect and during a feed on a new host.

It is unfortunate to note that in addition to the many natural methods of pathogen spread, human beings are also involved, and this association is now occurring at rates not seen previously. Much of it is associated with the international trade of plants and plant parts, whether as ornamentals or for propagation as seeds or cuttings. Local spread occurs too. Farmers often unwittingly spread pathogens in or on planting materials - the cuttings of *bele* or cassava, the corms of taro and banana, vines of sweet potato, or sets of yam. Careless use of agricultural machinery harbouring pathogen-contaminated soil is yet another way that human beings assist pathogens to spread.

5. Pathogens have many ways of surviving

To survive and pass their genes to the next generation is clearly an aim of all pathogens. Many methods are used by the groups described in this manual to ensure that it occurs. Your trainees should become acquainted with the methods associated with some of the main diseases in the region where PHCs are held. It is important to discuss survival of plant diseases with farmers because IPDM relies heavily on disrupting pest life cycles to achieve success. For instance, healthy planting material is a must, as is the destruction of harvest remains if they are likely to harbour pathogens for future crops.

Some methods of survival are listed below:

- In or on seeds (fungi, bacteria and viruses)
- In plant trash on or in soil (fungi and bacteria)
- On weeds – all
- On 'volunteer' (self-sown or those remaining from the previous harvest) plants – all
- On over-lapping crops – all
- As dormant spores or eggs in soil **–** fungi and nematodes
- Inside insects – viruses, some bacteria

2.7 Symptoms of pathogens – what can they tell us?

Fungi, oomycetes (fungus-like, *Phytophthora*, *Pythium* and relatives), bacteria, phytoplasmas, viruses, viroids and nematodes which collectively we call pathogens, commonly cause **symptoms** when they infect plants**.** These symptoms are important in helping us to diagnose plant diseases, so here we look at the type of symptoms that they produce.

Spots and shot-holes

Leaf spots are common and mostly caused by fungi. The spots grow to a particular size and then stop (Fig. 2.78). Spores develop on the underside of the leaves as furry patches, or inside black sacs embedded in the top surface. In both types, the spores are spread by wind and rain.

When the centre of the spots fall out,which is typical of some diseases, we call it a shot-hole (Fig. 2.78 top right). It is hard to tell fungal spots from those caused by bacteria (Fig. 2.78 bottom left) without studying them in the laboratory. Viruses occasionally develop ringspots (Fig. 2.78 bottom right) but, as with bacterial spots, they are rare.

Fig. 2.78 Examples of spots and shot-holes. (Top left) spots (fungus) on coconut. (Top right) spots (fungus) on taro. (Bottom left) Tomato with a bacterial infection. (Bottom right) spots (virus) on sweet potato.

Blights

Some spots do not stop growing and the symptoms develop into a blight. Blights are typically wet-weather diseases, such as taro leaf blight (Fig. 2.79 left), watermelon gummy stem blight (Fig. 2.79 right) and yam dieback. Spots develop, expand and form masses of spores, which spread rapidly, infecting and defoliating leaves and killing stems.

Fig. 2.79 Examples of blights. Taro leaf blight (left) and gummy stem blight on watermelon (right). These blights can totally destroy their respective crops in a few days of wet weather.

Mildews

There are two kinds of mildew - powdery and downy. Powdery, as the name suggests, causes white growths over leaves, common on cucurbits and okra in Fiji (Fig. 2.80 left), and rose in Tonga, during dry weather. The fungus forms long chains of oval spores that stand erect from the leaf, giving it a powdery appearance. These mildews are unusual fungi as they grow on the outside of leaves and feed from organs that penetrate the leaf surface to feed on cells inside. Their spores do not germinate well in water, they just need high humidity.

Downy mildew is different. It is not a fungus, but an oomycete or water mould, related to algae. It needs water for the spores to germinate. Downy mildew of cucumber (Fig. 2.80 right) and squash (especially in Tonga) is the common example in the Pacific region. Typically, the mildew forms squarish or rectangular areas on the top of the leaf that are yellow at first and then turn brown. Patches of greyish/brown occur below where the spores develop. *Phytophthora* and *Pythium* (common on taro causing blight and wilt, respectively), are also oomycetes.

Fig. 2.80 (Left) powdery mildew on okra. (Right) downy mildew on the underside of cucumber leaf where spores are produced; the upper surface (inset bottom right) has the same 'squarish' infections confined by the veins, but are yellow.

Wilts

Wilts can be caused by fungi, oomycetes, bacteria and nematodes. It is difficult to tell which is the cause from symptoms alone, unless you are familiar with the disease on a certain crop. Experience will help you to know what diseases are common on different crops (Fig. 2.81).

Fig. 2.81 (left) The disease is caused by a fungus, *Phellinus*, common on cocoa, causing a wilt. In Fiji the fungus grows through the soil, infects the roots and kills them. Leaves wilt and the crust-like fungus grows up the cocoa trunk (right).

For instance, a wilting cocoa plant would suggest *Phellinus*, a soil-borne fungus (Fig. 2.81); a wilting taro, *Pythium*, an oomycete that destroys the fine roots (Fig. 2.82 left); and a wilting tomato would suggest a fungus (e.g. *Athelia*) or a bacterium (e.g. *Ralstonia*, bacterial wilt). Examination of the wilted plants would be needed to decide the cause.

Symptoms of wilt can be confusing to farmers. Usually, the roots are diseased and the leaves droop down or collapse, as they lack water. Farmers and plant health doctors might mistake the symptoms on the leaves for the cause of the problem, so suggest that if they see wilted plants they inspect the roots. Dig up the plant carefully, wash the roots and look for death and decay of the fine, side roots; these are the ones that take in water and nutrients from the soil. Without them, leaves collapse.

Remember, insects can damage roots, too. For instance, *Papuana* beetles cause a wilt when they attack the young roots and corms of taro (Fig. 2.82 right).

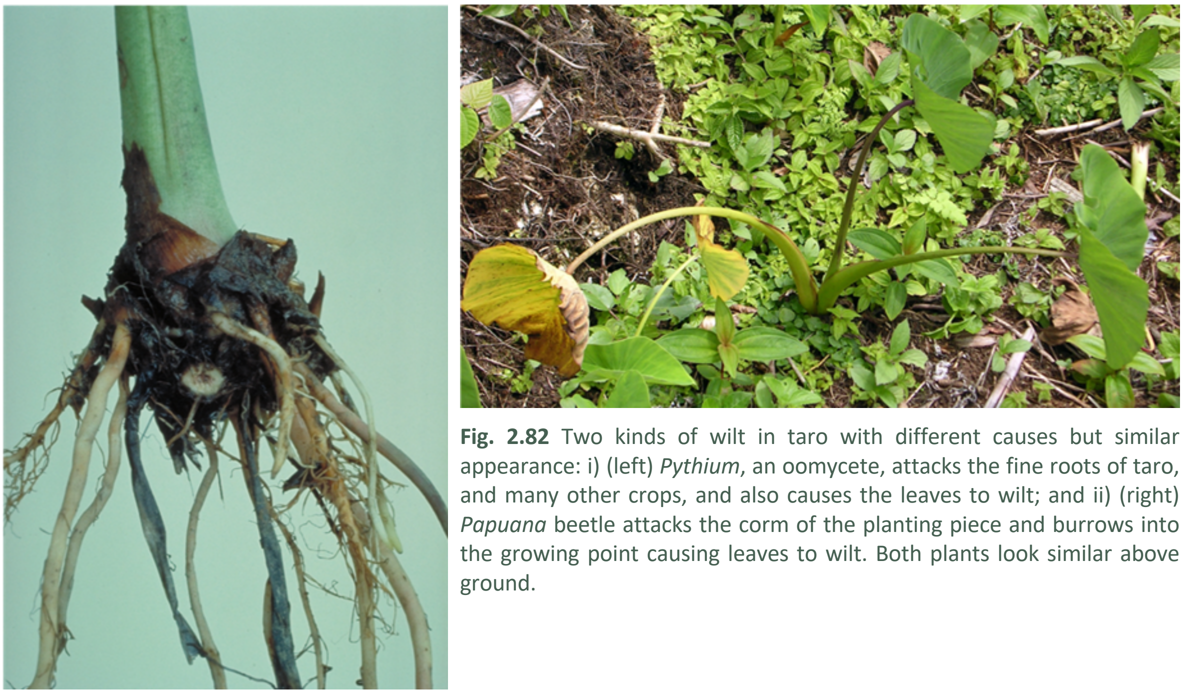

Fig. 2.82 Two kinds of wilt in taro with different causes but similar appearance: i) (left) *Pythium*, an oomycete, attacks the fine roots of taro, and many other crops, and also causes the leaves to wilt; and ii) (right) *Papuana* beetle attacks the corm of the planting piece and burrows into the growing point causing leaves to wilt. Both plants look similar above ground.

Damping-off

Damping-off is a special case of wilt that affects seeds and seedlings. There are two kinds of damping-off: **pre-emergence**, when seeds or seedlings are killed before they reach the soil surface; and **post-emergence**, when they die soon afterwards (Fig. 2.83). Often, fungi and oomycetes are involved. When the disease occurs in a nursery, it is likely that the soil has not been pasteurised.

Fig. 2.83 Damping-off showing both pre- and post-emergence symptoms where the seedling are killed either before or after they have penetrated the soil surface. Fungi are usually the cause and are common in nurseries if the soil has not been pasteurised.

Canker

A canker is an area on a branch or trunk that is dead in the centre and alive at the edges, where it expands slowly. There may be gum at the edges. Fungi, oomycetes or bacteria are the likely cause. Cankers on cocoa are often seen as a result of the oomycete *(Phytophthora)* that causes black pod disease growing back into the branch or trunk (Fig. 2.84).

Fig. 2.84 Canker on cocoa*. Phytophthora* has grown from the pod into the branch.

Smuts

Smuts infect cereal crops and grasses. They are not common in the Pacific region. In Pacific islands countries, boil smut might be seen (Fig 2.85) but only in Solomon Islands and Papua New Guinea. Spores of the fungus are in the soil; they germinate, infect and grow inside the plant, reaching the cob, where the seeds are transformed into a mass of black spores. Small galls occur on the leaves.

Fig. 2.85 Smut on maize. The seeds in the cob have been transformed into masses of black spores.

Rusts

When leaves with rust are stroked with a finger, a brownish/orange colour is left behind, hence the name, rust. The powder is a mass of spores formed by the rust fungus in numerous leaf pustules. Rusts have complex life cycles; there are several stages and, for some, the life cycle involves two unrelated hosts. Spores are able to travel high in the atmosphere and spread over large distances. Breadfruit, yams, peanuts (Fig. 2.86 left), maize (Fig. 2.86 right) and many other plants have rust diseases in Pacific island countries.

Fig. 2.86 Rusts: (left) pustules on the underside of peanut leaflets; (right) pustules on the top of a maize leaf.

Yellows and distortions

The word 'mosaic' is often applied to virus diseases that cause yellowing or distortions of the leaves. It describes the patches of yellow or light green mixed with the normal green colour on infected leaves. Mosaic symptoms occur commonly on yam, *bele* (slippery cabbage), sweet potato (Fig. 2.87 left), chilli, taro and beans (Fig. 2.87 right). On monocotyledonous plants, mosaics occur parallel to the main veins, and therefore as stripes. It is commonly seen in maize infected with maize mosaic virus where bands of green and yellow occur from the base to the tip of the leaf.

Fig. 2.87 Mosaics: (left) Faint patterns of yellow amongst the green of sweet potato leaves; (right) yellow and green patterns with distortions on leaves of long bean.

Sometimes, colour changes are just seen along the sides of major veins, as in virus diseases of taro, or in stripes parallel to the veins, as in maize and banana.

Often, viruses also cause distortions. Taro infected with *Alomae* or *Bobone* is a good example (Fig. 2.88 left). In this case, infections can be caused by several viruses, and symptoms depend on the number and type present. Less severe are the crinkles and bumps that occur on leaves or fruits, such as those seen on zucchini.

Distortions are also produced by phytoplasma infections. Phytoplasmas are spread by insects (often leafhoppers) and cannot be grown in the laboratory on artificial media. Different kinds occur on coconuts throughout the world, and In recent years, coconuts near Madang, PNG, have also been found infected with phytoplasmas. It seems that the same phytoplasma also infects banana, causing leaves to yellow. Yellowing of leaves is just one symptom caused by phytoplasmas; more common is little leaf, for example on sweet potato (Fig. 2.88 right) and legumes.

Fig. 2.88 Distortions and little leaves: (left) young leaves of taro with *Alomae*; a lethal virus disease; (right) little leaf symptom on sweet potato caused by a phytoplasma.

Post-harvest/storage diseases

Just as diseases infect plants in the field, they also occur after harvest. They are especially common in corms, storage roots, tubers and many kinds of fruit and vegetables. Few harvested crops stay uninfected for more than a few days after harvest. Wounds caused at harvest make the produce susceptible to infection by fungi, bacteria and also nematodes. Many species are involved. In some cases, rots in the field continue in storage, for example, *Pratylenchus* (nematode) on yam, and *Pythium* (oomycete) on taro (Fig. 2.89). Other rots, such as those on citrus (*Penicillium*), mango (*Colletotrichum*) start after harvest. Some insects, especially beetles and weevils, also cause post-harvest rots.

Fig. 2.89 Post-harvest rots: dry caused by nematodes (left) and taro with two rots (right): *Pythium* is the cause of the whitish rot at the base, and *Athelia* the white cottony growth on the left side.

A WARNING

Some symptoms can be misleading

Example 1: Sooty mould is not a disease but is caused by fungi growing on honeydew from aphids, mealybugs and scale insects

Example 2: Cassava roots blacken after harvest due to physiological (chemical) processes

Example 3: Taro corms shrivel after harvest through water loss

EXERCISE 5: Using symptoms to make a diagnosis

Now that your trainees have more information about pests and pathogens, they should collect their samples from Exercise 2 tables A, B and C and have another look at them using a hand lens. Trainees should carefully and clearly describe all the symptoms (signs) on the plant and try to make a diagnosis.

Trainees should copy and complete the table below and fill in the last column after discussion.

Table 2.4 Using symptoms to make a diagnosis.

Crop	Plant part affected (leaf, stem, fruit, root, other)	Symptoms/signs DESCRIBE VERY CAREFULLY AND CLEARLY	Diagnosis: possible causes with reasons	Actual cause (Fill in AFTER class discussion)
Example: *Rose*	*Leaf, stem, flower bud*	*Grey/white powder on the stalk and bud of the flower. It is not present on the older parts of the plant.* *Looks like dust*	*Mildew – a fungus that grows on the outside of leaves and stems (and buds)* *Dust from the road*	*Powdery mildew (Podosphaera pannosa). Spores can be seen with the hand lens*

EXERCISE 6: What have you learned about pests and diseases?

In pairs or threes, trainees should complete this table. Some cells have been filled in as an example. They should check their answers with another group, then discuss the answers as a class.

Table 2.5 What have you learned about pests and diseases?

	Fungi	Bacteria	Viruses	Nematodes	Insects
Size – can they be seen with the naked eye?		*No*			
How do they reproduce?	*Spores*				
How do they spread?					
How do they survive?			*In living cells*		
What are some typical symptoms/signs on plants?		*Wilts*			

2.8 Most common crops and diseases in your region

It is very important that before the clinic, plant health doctor trainees become familiar with crops commonly grown in the area where the plant health clinic is to be held, so that they can be prepared. Once these crops are identified, they should use the Pacific Pests, Pathogens & Weeds app for those that they are not familiar with. See also Section 3.3 in Chapter 3. Remind trainees always to be prepared for something new!

Some of pests and pathogens of common crops in Samoa are given in Table 2.6 and in Tonga in Table 2.7.

Table 2.6 Some common pests and pathogens of crops in Samoa with Fact sheet numbers

SAMOA	
Crop	**Fact Sheet (pest/pathogen or disease)**
Banana	• Black Sigatoka (002) • Bunchy top (121) • Burrowing nematode (257) • Leaf spot (309) • Scab moth (017) • Weevil (109)
Beans	• Lace bug (253)
Cabbage	• Diamondback moth (020) • Centre grub (114) • Cluster caterpillar (LCM) (078) • Club root (283) • Black rot (204)
Chinese cabbage	• Diamondback moth (see under cabbage) (20) • Centre grub (see under cabbage) (114) • Cluster caterpillar (LCM) (see under cabbage) (78) • Stalk rot (101)
Citrus	• Tristeza disease (250) • Fruit-piercing moth (113) • Scab (048)

Cocoa	• Black pod (006) • Pink disease (012)
Coconut	• Hispine beetle (059) • Rhinoceros beetle (108) • Embryo rot (070)
Mango	• Anthracnose (009) • Seed weevil (353)
Papaya	• *Phytophthora* fruit and root rot (152)
Passionfruit	• Woodiness (156) • Spots (153) • Southern blight (011)
Peanut	• Southern blight (011) • Rust (034) • Leaf spots (036)
Pineapple	• Wilt disease (380)
Solanaceae (tomato, capsicum, eggplant)	• Bacterial wilt (081) • Root-knot nematode (254) • Frog-eye spot (092) • Target spot (163) • Fruit-piercing moth (113) • Leaf mould (076) • Spider mites (024) • Broad mites (049) • Southern blight (011)
Taro	• Root rot (044) • Rhabdovirus diseases (089)

Table 2.7 Some common pests and pathogens of crops in Tonga with Fact sheet numbers.

TONGA	
Crop	**Pest/Pathogen**
Yam	• Rose beetle (107) • Anthracnose (016) • Scale (post-harvest) (093) • Dry rot (nematode) (008)
Cucurbits (cucumber, melon, watermelon, squash, zucchini, etc.)	• Cucumber moth (033) Watermelon gummy stem blight (007) • Downy mildew (143) • Powdery mildew (063) • Leaf miner (262) • *Corynespora* leaf spot (189) • Zucchini mosaic virus (202) • Papaya ringspot virus-W (392)
Cabbage	• Large cabbage moth (078) • Diamondback moth (020) • Damping-off (047) • Basal stem rot (101)
Cassava	• Spiralling whitefly (025) • White peach scale (052)
Banana	• Banana weevil (109) • Banana scab moth (017) • Black Sigatoka (002) • Banana bunchy top virus (121) • Banana burrowing nematode (257)
Coconut	• Coconut flat moth (065) • Coconut rhinoceros beetle (057) • Coconut stick insect (102)
Tobacco	• Frog-eye spot (304)
Sweet potato	• Weevils (029 & 119) • Sweet potato whitefly (284) • Little leaf (055) • Scab (013)

Solonaceae (tomato, capsicum, eggplant)	• Fruit flies (171) • Fruit-piercing moth (113) • Anthracnose (177) • *Corynespora* target spot (163) • Bacterial wilt (146) • Leaf moulds (045 & 076) • Spider mites (024)
Taro, giant taro, Xanthosoma	• Cluster caterpillar (031) • Taro hornworm (032) • Aphids (038) • *Pythium* wilt (044)
Kava	• CMV dieback (160) • Nematode (254)
Papaya	• Papaya crown rot (172) • Phytophthora fruit & root rot (152)
Bean	• Aphids (356) • Bean pod borer (037) • Green vegetable bug (098)
Maize	• Rust (042 & 225) • Maize mosaic virus (074)

EXERCISE 7: Complete this table for your own country.

In pairs or threes, your trainees should complete this table for the most common pests and diseases in their country. If the country is one of the examples listed in Tables 2.6 or 2.7, they should add some crops with their pests and diseases that may have been missed. They should share their answers to develop a good profile of their country's most common pests and diseases.

Country:	
Crop	**Three (or more) important pests/diseases**

EXERCISE 8: Completing a 'stem' table (optional exercise)

This exercise helps your trainees to summarise their learning so far about pests and diseases.

Trainees should do this on their own or in pairs. It is like completing a sentence (the 'stem' is the beginning of the sentence). Starting with the first column (Insect Pests), they fill in the answers. Then they fill in the second column (Nematodes) and so on, until the table is completed.

There will be many correct answers. A few cells have been filled in as examples.

	Insect Pests	Nematodes	Nitrogen Deficiency	Viruses	Fungi	Bacteria	Drought
Are:				*Very small*			
Are not:		*an insect*					
Can:							
Cannot:	*Produce spores*						
May cause:						*Wilting*	
Does not cause:					*Chewing of leaves*		
Can be controlled by:							
Cannot be controlled by:			*Fungicide*				*Fertiliser*

EXERCISE 9: What am I?

This exercise can be as easy or as difficult as you decide to make it. Make a list of the words that you would like your trainees to understand. The exercise can be carried out at any point during the training to strengthen your trainees' learning.

Write words associated with plant protection (see below) on cards, and stick one on the back of each trainee with masking tape. They are not allowed to look at it! Trainees then move around the room asking other trainees questions to find out what the word is. The other trainees can ONLY answer "yes", "no" or "sometimes/maybe". If, after a while, people are having difficulty, clues may be given.

Trainees should sit down after they have found the correct answer. Discuss how difficult or easy it was to find the right answer, and why.

Some examples of words you could use:

- Bacteria
- Rhinoceros beetle
- Phytoplasma
- Potassium deficiency
- Rust
- Aphid
- Spore
- Weed
- Snail
- Mite
- Sooty mould
- Fall army worm
- Leaf spot
- Wilt
- Drought
- Nematode
- Mosaic
- Abiotic
- Soil
- Variegation
- Virus

2.9 Making a diagnosis: symptoms, possibilities and probabilities

It is very important for plant health doctors to be able to work through a process of 'possibilities and probabilities' in diagnosis to be able to give good advice to the farmers. Some problems are easy to diagnose, especially pests that you can see; others are difficult. As well, some plant problems may have similar symptoms. For example, yellowing of leaves can be due to nutrient deficiency and can also be due to fungal or bacterial disease.

Do I need to know the names of everything?

No!

Specific diagnosis, like that of the name of the insect or fungus, is not always possible and it is not really necessary

Farmers do not need to know scientific names, but **they do need to know the pest or disease *type*** to give them an understanding of the information and management recommendations

E.g. Farmers do not need to know that the scientific name of the nematode in yams with dry rot is *Pratylenchus coffeae.* It is enough to know that it is a nematode and why hot water treatment is recommended (and how to apply it)

2.9.1 Using the possibilities and probabilities process to diagnose a problem

Now that your trainees have some knowledge of pests and diseases, they can look at symptoms to see if they are distinctive in any way in order to develop a diagnosis. The best approach to making a diagnosis is to think like a detective! What is likely or unlikely to be the cause; what is possible or what is probable?

Successful diagnosis can be difficult because there are so many insects, mites, pathogens and abiotic causes, and plants respond to them in different ways. However, diagnosis is essential for good management.

Use the examples and exercises below to build your trainees' confidence in their ability to make correct diagnoses. They should practise these steps as often as they can with a range of different pest and disease samples.

Work carefully through the following possible and probable causes process with your trainees, using eggplant as the example. Once you think they have understood the process, ask them to complete Exercises 10, 11 and 12.

EXAMPLE: Blotch symptoms on eggplant

Symptoms:

1. Dark blotches on the fruit.

2. The spots/blotches are roughly circular.

3. Minute black dots in the spots: possibly containing spores.

4. Spots dispersed over the fruit and merging together.

Possible causes	Possible? ✓✘	Probable? ✓✘	Why did you decide this?
BIOTIC			
Insects	✓	x	No insects found and no frass, but could be secondary infection after sucking insects.
Mites	✘	✘	No mites found and not typical of mite symptoms.
Fungi	✓	✓	Fungi cause spots/blotches on eggplant, and fungal fruiting bodies present.
Bacteria	✓	✘	Bacteria may cause spots/blotches on eggplant, so could be a new disease, but fungal fruiting bodies suggest not bacterial.
Virus	✘	✘	Not a typical symptom for virus.
Phytoplasma	✘	✘	Not a typical symptom for phytoplasma.
Nematode	✘	✘	Not a typical symptom and most nematodes are on roots.
Weeds	✘	NA	NA for these symptoms
Parasitic plants	✘	NA	NA for these symptoms
Slugs & Snails	✘	✘	Absence of chewing and slime trails.
Mammals	✘	✘	Absence of scratching or chew marks.
Birds	✘	✘	Would expect to see pecking damage.
ABIOTIC			
Nutrient deficiencies	✘	NA	NA for these symptoms
Sun scald	✘	NA	NA for these symptoms
Water (too much or too little)	✘	NA	NA for these symptoms
Lightning	✘	NA	NA for these symptoms
Herbicide	✘	NA	NA for these symptoms
It's natural	✘	NA	NA for these symptoms

NA = not applicable in this case
X = not possible for this symptom

NOTE: This is likely to be anthracnose caused by *Colletotrichum*. There is a fact sheet in the Pacific Pests, Pathogens & Weeds app (no. 50). Yes, a bacterial cause is a possibility, but the probability for a fungus is higher. *Colletotrichum* spots are common on eggplant fruits, but bacterial spots are unknown. Also, inside the large black areas there are tiny round black structures which are likely to contain fungal spores.

EXERCISE 10: Using the possible and probable approach

In pairs or threes, now work though this example, following the steps above. Then check your answer with the Pacific Pests, Pathogens & Weeds app. Discuss with the rest of the class.

EXAMPLE: large blotches on cassava leaves

Symptoms:

1.

2.

3.

4.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why did you decide this?
BIOTIC			
Insects			
Mites			
Fungi			
Bacteria			
Virus			
Phytoplasma			
Nematode			
Weeds			
Parasitic plants			
Slugs & Snails			
Mammals			
Birds			
ABIOTIC			
Nutrient deficiencies			
Sun scald			
Water (too much or too little)			
Lightning			
Herbicide			
It's natural			

NOTES:

Now check your answer with the Pacific Pests, Pathogens & Weeds app.

- What is your diagnosis?

- Do you still need more information? What information do you need and why?

- What would you ask the farmer who brought this sample in?

Discuss with the class:

REMEMBER

When working with farmers, NEVER go straight to the Pacific Pests & Pathogens & Weeds app.

ALWAYS work through the ABC activity and then the possibilities and probabilities process in your mind first!

EXERCISE 11: Using the possible and probable approach

In pairs or threes, now work though this example following the steps above. Then check your answer with the Pacific Pests, Pathogens & Weeds app. Discuss with the rest of the class.

EXAMPLE: yellowing on sweet potato

Symptoms:

1.

2.

3.

4.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why did you decide this?
BIOTIC			
Insects			
Mites			
Fungi			
Bacteria			
Virus			
Phytoplasma			
Nematode			
Weeds			
Parasitic plants			
Slugs & Snails			
Mammals			
Birds			
ABIOTIC			
Nutrient deficiencies			
Sun scald			
Water (too much or too little)			
Lightning			
Herbicide			
It's natural			

NOTES:

Now check your answer with the Pacific Pests, Pathogens & Weeds app.

- What is your diagnosis?
- Do you still need more information? What information do you need and why?
- What would you ask the farmer who brought this sample in?

Discuss with the class:

Exercise 12: Using the possible and probable approach to diagnosis

In pairs or threes, now work though this example, following the steps above. Then check your answer with the Pacific Pests, Pathogens & Weeds app. Discuss with the rest of the class.

EX thosoma leaves

Symptoms:
1.
2.
3.
4.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why did you decide this?
BIOTIC			
Insects			
Mites			
Fungi			
Bacteria			
Virus			
Phytoplasma			
Nematode			
Weeds			
Parasitic plants			
Slugs & Snails			
Mammals			
Birds			
ABIOTIC			
Nutrient deficiencies			
Sun scald			
Water (too much or too little)			
Lightning			
Herbicide			
It's natural			

NOTES:

Now check your answer with the Pacific Pests, Pathogens & Weeds app.

- What is your diagnosis?

- Do you still need more information? What information do you need and why?

- What would you ask the farmer who brought this sample in?

Discuss with the class:

END OF CHAPTER 2 QUIZ: Test your knowledge.

Multiple choice. Pick one answer only.

1. In ORDER, abiotic and biotic factors that cause damage on plants are:

A. a fungus and a mite
B. a bird and drought
C. potassium deficiency and bacteria
D. phytoplasma and poor soil

2. Symptoms on tomatoes and cabbages caused by bacteria are:

A. leaf spots and evenly spread leaf yellowing
B. wilt and V-shaped yellowing at the edges of leaves
C. rust spots and mosaics
D. dieback and with leaves going purple

3. A common disease of tomatoes in the Pacific is:

A. witches' broom
B. tobacco mosaic
C. early blight
D. ring spot

4. The smallest of these pathogens is:

A. virus
B. phytoplasma
C. bacterium
D. fungal spore

5. A plant doctor finds a plant with symptoms of wilt. The most <u>unlikely</u> cause would be:

A. bacteria in the soil
B. powdery mildew
C. nematodes
D. stalk borer

6. Pests with eight legs are:

A. mites
B. insects
C. nematodes
D. millipedes

7. Which of these diseases is caused by a fungus?

A. bunchy top on banana
B. blossom end rot on tomato
C. citrus canker
D. damping-off on cabbage seedlings

8. A plant doctor finds a cabbage with a lot of holes in the leaves. Which are not possible causes?

A. diamondback moth
B. large cabbage moth
C. leaf chewing nematodes
D. snails

9. A virus cannot usually be spread between plants by:

A. nematodes
B. tools
C. rhinoceros beetles
D. aphids

10. Two insects with complete life cycles are:

A. aphids and beetles
B. butterflies and bugs
C. grasshoppers and ants
D. bees and moths

11. Where do you find the eggs of this spiralling whitefly?

A. inserted into the leaf
B. whiteflies do not lay eggs, they give birth to living young
C. in the waxy spirals
D. underneath the female whiteflies

12. What is the most likely cause for this hibiscus wilt?

A. mites or thrips have attacked the young leaves, and they have wilted
B. it was planted on a slope, and there has been a long drought
C. old age
D. a fungus or an insect is destroying the roots