Discovery Learning Manual For Cabbage Pest Management

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CAB International

A compilation based on three publications of CAB International:
Crop Protection Compendium
Vegetable IPM Exercises
Understanding Natural Enemies

About this manual

Integrated Pest Management (IPM) and Integrated Crop Management (ICM) strategies are now widely recognized as key components in the move towards more sustainable and environmentally friendly approaches to crop production. In many developing countries however, these knowledge intensive strategies have not been widely adopted by farmers. To address this concern, Farmer participatory (FP) approaches to training and research are fast gaining acceptance.

The FP approach aims to build farmers' capacity to make their own crop management decisions, based on a better understanding of the agro-ecology of their own fields, and according to their own unique set of circumstances and priorities. This is in direct contrast to more conventional extension approaches where research recommendations are passed on to farmers in a top down manner. With FP approaches, the role of the extension service becomes more of a facilitator of a learning process by the farming community, and less of a messenger from the research community.

FP approaches rely heavily on non-formal education methods, and learning through doing, generally known as discovery learning. This manual provides technical information on major cabbage pests and beneficials and a range of discovery learning exercises and field experiments. It is aimed principally at National IPM programmes, IPM trainers, farmer trainers, and others interested in IPM training and farmer participatory approaches.

This manual draws heavily on three existing resources:

1. **Crop Protection Compendium, CABI**
   An interactive, multimedia knowledge base available on CD-ROM and on the Internet, containing a wide range of science-based information on all aspects of crop protection.

2. **Vegetable IPM Exercises: Protocols, Implementation and Background Information. (1998) JGM Vos, CABI Bioscience/FAO. pp 674**
   A manual of IPM exercises developed for the FAO Regional project for IPM of vegetables in Asia.

3. **Understanding Natural Enemies. Working with Natural Enemies Series, Bulletin No 1. (2001) Technical Support Group CABI Bioscience. pp 74**
   A training bulletin explaining the basic principles of biological control in a non-specialist way.

This Discovery Learning Manual aims to complement the Cabbage Integrated Pest Management: An Ecological Guide, developed by F.M. Praasterink, independent consultant to FAO.

The manual also aims to test whether a science-based electronic knowledge resource such as the Crop Protection Compendium can provide a satisfactory source for a learning manual in a farmer participatory context.

The manual consists of two major parts: Part I (sections 2, 3 and 4) provide the technical background on the biology and management of some major key pests (including diseases) and beneficials, linked to a set of farmer participatory exercises in Part II (sections 5, 6 and 7). Most exercises have been field-tested in one or several countries in Asia and Africa.

The information in either Part I or II is not intended to be comprehensive. Rather, Part I should be viewed as supporting the exercises in Part II, which are designed to facilitate an understanding of the ecological principles underpinning pest ecology and management through experimentation. By the same token, the exercises should be viewed as guidelines and sources of inspiration rather than as rigid instructions. We hope that the manual will have global relevance, as the exercises can and should be adapted to local conditions, such as available materials, prevalent pest problems, local knowledge and experience within the farming community.

A manual such as this is never truly finished. It needs to be constantly updated as practitioners around the world modify existing exercises and develop new ones. As compilers of this manual, we would like to ask for your help in keeping us abreast of new developments and informed of modifications or additional materials.

Future development

Modifications and additional materials are requested to be sent to the editors at CABI International.

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D Agassiz (*Agrotis segetum, Hellula undalis*); ARS/USDA (*Helicoverpa zea*); Aventis CropScience (*Campoletis* sp., *Heliothis virescens, Mamestra brassicae, Pieris brassicae, Plasmodiophora brassicae, Pythium*); ID Bedford (*Bemisia tabaci, Eretmocerus* sp. on *B. tabaci*); Biologische Bundesanstalt Dossenheim (*Spodoptera littoralis*); Nigel Cattlin/Holt Studios (*Aphidius* sp., aphid parasitized by *Aphidius* sp., *Cotesia plutellae, Diadegma semiclausum, Encarsia formosana, E. formosa, Myzus persicae, Pieris rapae, Plutella xylostella, Spodoptera exigua*); A Cherry (*Diadegma insulare*); Ching-Chin Chien (*Pachyneuron muscarum*); CIMMYT (*Helicoverpa zea*); M Cock (*Aleurodicus dispersus*); Cornell University (*Crocidolomia pavonana*); CSL (*Agrotis segetum*, *Brevicoryne brassicae, Episyrphus balteatus, Liriomyza trifolii, Pieris brassicae*); AMI de Farias (*Aphelinus asychis*); Denver Natural History Museum (*Exorista bombycis*); SV Fowler (*Pardosa*); G Goergen/IITA Insect Museum (*Spodoptera littoralis*); KM Harris (*Aphidoletes aphidimyza*); S Hassan (eggs parasitized by *Trichogramma*); Y Hirose (*Thrips palmi*); M Holderness (*Peronospora parasitica*); WF Hsiao (*Crocidolomia pavonana*); ICRISAT (*Helicoverpa armigera, Spodoptera litura*); Iowa State University (*Xanthomonas campestris* pv. *campestris*); DG James (*Pieris rapae*); ABS King (*Helicoverpa armigera*); Clive Siu Ki Lau (*Phyllotreta striolata*); H Legutowska (*Thrips tabaci*); J Litsinger (*Micraspis crocea, Solenopsis geminata, Tetrastichus schoenobii*); M Mazzotti (*Trichogramma brassicae*); CM Mguni/C Nieves (*Xanthomonas campestris* pv. *campestris*); Natural History Museum, London (*Brachymeria* sp.); E Neering (*Spodoptera litura*); J Ogrodnick (*Orius* sp.); A Polaszek (*Telenomus* sp.); J Porter (*Agrotis segetum*); A Shelton (*Trichoplusia ni*); AL Snowdon (*Alternaria brassicicola*); KA Spencer (*Liriomyza sativae, L. trifolii*); JP Tewari (*Alternaria brassicicola*); University of Nebraska-Lincoln (*Agrotis ispilon*); USDA (*Coccinella septempunctata*); J Waller (*Alternaria* leafspot); Yu Yan-fen (*Thrips tabaci, T. palmi*).

Contents

Part I
Information Sheets on Major Key Cabbage Pests and Beneficials

1. Introduction

1.1 The cabbage plant

Cabbages belong to a large and diverse family of plants called the Cruciferae. This family contains a wide range of crops including cabbages, cauliflower, coles, kales, Brussels sprouts and broccoli. There are two main species of cultivated cabbage: the white or head cabbage *Brassica oleracea* (variety capitata) and the Chinese cabbage *Brassica rapa* (sub species *Chinensis*), although there are currently many varieties of both species grown. The Cruciferae family contains many wild plants of which some are important weeds while others may harbour pests, enabling them to survive from one susceptible crop to the next.

1.2 Cabbage production

Cabbages are grown all over the world, and are an important component in the diets of millions of people in Africa, Asia, the Americas, Europe and the former Soviet Union. In 2000, the world production was about 52.3 million tonnes of which over a third was produced in China.

Cabbage grows best on light to medium-heavy soils at an optimum pH of 6.0-7.5. They are grown from seed and often raised in nurseries and transplanted out into the field when the seedlings are about 3-5 cm tall.

1.3 Crop development

Presently there is no standard terminology for describing cabbage growth stages like there is for some other crops such as rice. Although terms such as “head formation” and “cupping” do exist, it can be confusing because this terminology is often regional and can vary among farmers and others involved in agriculture. Accurate cabbage growth stage descriptions are particularly useful in pest management since plant susceptibility to cabbage pests varies with the growth stage. We have used four growth stages: seedling, vegetative, head formation and mature stage, but of course local farmer classification should be used whenever available.

1.4 Pests

Pests are an important constraint to cabbage production in most cropping areas. The CABI Crop Protection Compendium lists 145 insects and diseases attacking cabbage. Fortunately, only a smaller number of these are of economic importance. We will focus on some of the key problems for the remainder of this manual. Table 1 aims to provide an overview of some of these key pests and the stages of development at which these might be important. Please bear in mind that this is not intended to be a comprehensive list. We have focused on those problems that frequently affect cabbage in a global context. The severity and importance of these problems will, of course, vary from region to region, and problems that are very significant in the specific areas in which you work, may not be represented here. Nevertheless, many of the exercises provided can be adapted to pests other than those included in this manual.

Monitoring is a key factor in ecological crop management, and this table should be used as a rough guide as to when to look out for what.

Table 1. When are cabbages most susceptible?

Crop highly susceptible - Intensive monitoring required Crop less susceptible – Less intensive monitoring required

Growth stage → **Pest ↓**	**Seedling** 	**Vegetative** 	**Head formation** 	**Mature** 
Damping-off (*Pythium* sp.)				
Flea beetles (*Phyllotreta* sp.)				
Cutworms (*Agrotis* sp.)				
Leafminers *Liriomyza* sp.				
Green peach aphid *Myzus persica*				
Thrips *Thrips* sp.				
Downy mildew (*Peronospora* sp.)				
Webworms (*Hellula* sp.)				
Cabbage moth *Mamestra brassicae*				
Diamondback moth (*Plutella xylostella*)				
Cabbage worms (*Pieris* sp.)				
Clubroot (*Plasmodiophora* sp.)				
Black rot (*Xanthomonas* sp.)				
Black leg (*Phoma lingam*)				
Bottom rot (*Rhizoctonia* sp.)				
Heart caterpillar (*Crocidolomia* sp.)				
Aphids (*Brevicoryne* sp.)				
Bollworms *Helicoverpa* sp.				
Cabbage looper (*Trichoplusia ni*)				
Armyworms (*Spodoptera* sp.)				
Whitefly (*Bemisia* sp.)				
Leaf spot (*Alternaria* sp.)				
Soft rot (*Erwinia carotovora*)				

2. Pest Fact Sheets

2.1 Cutworms - *Agrotis* spp.

Importance

Cutworms are caterpillars of different moths that usually cut young plants at ground level. Here two widespread species are described: the common cutworm *Agrotis segetum* and the black cutworm *A. ipsilon* (Figs. 1 and 2). Cutworms are pests of many cultivated crops like corn, rice, potatoes and vegetables, including cruciferous plants. They attack the leaves, stems and roots of plants, affecting the seedling and growing stages. Losses are due to the destruction of seedlings or to non-marketable stems, roots or tubers.

Fig. 1. World distribution of common cutworm

Fig. 2. World distribution of black cutworm

Early stages of the larvae attack the leaves in groups, feeding on the upper surface and the inside of the leaf, causing 'windowpanes' where only the lower surface of the leaf remains. Later larval stages become more solitary, real cutworms and cause more severe damage resulting in the leaves falling off the plant or even causing whole plants to fall over. When disturbed caterpillars curl up.

Description

Cutworm eggs

Eggs

The small (0.5 mm diameter), round eggs of the common cutworm are mainly laid in clusters on the underside of weeds, dry plant residues or on lumps of soil. The eggs are pale when laid turning pinkish-brown later. The eggs hatch after 3-14 days depending on temperature. The emerging larvae move to the top of the plant where they are transported to new plants by the wind.

Larvae

There are six larval stages (instars), ranging from 3 to 45 mm in length and from greyish-brown to almost black in colour (see pictures below). Larvae generally have a greasy appearance. Lines along the body and marks on the head may serve to distinguish different species. The young cutworms are voracious feeders at night. During the day they roll up under a lump of soil or in the ground up to a depth of 12 cm. Larval stage lasts about 30 days depending on temperature.

Common cutworm larva

Common cutworm larva

Black cutworm larva

Pupae

The pupae are 15-30 mm long and 5-8 mm in diameter. The yellowish-brown to dark brown common cutworm pupae are a bit smaller than the dark red-brown black cutworm pupae. Pupation takes place in the soil and lasts 10-30 days.

Adult

Adult moths (pictures below) have a wingspan of 30-50 mm, the common cutworm being generally the smallest. The front wings are greyish to dark brown with different patterns of markings. The hind wings are white in the male and grey in the female, and have a dark terminal line. Common cutworms have a brown body, whereas that of the black cutworm is grey. Mating begins on the night of emergence. After 3-4 days, each female lays between 200 and 2000 eggs over about six days.

Common cutworm adult

Common cutworm adult

Ecology

There are generally one or two generations a year, but five or more generations have been reported in warmer climates. The total life cycle from egg to adult may take only 32 days at 30°C. The cutworms move from plant to plant at night, feeding on leaves and cutting the petioles. During the day they curl up under the lumps of soil, in cracks or below the soil surface.

The cutworms are voracious feeders and attack depends upon the soil structure, weather and temperature. Warm, dry conditions are favourable to attack and two warm dry seasons may result in very severe cutworm damage. Cutworms do not like harsh climates and they die at temperatures above 35°C.

Pest Management

Pheromone traps are useful for detection, also check under fallen leaves or look out for seedlings cut at ground level. Baits such as *Bacillus thuringiensis* (Bt) baits or wheat bran baits based on *Steinernema* could be explored.

Cutworm damage is less severe in humid areas of fields and irrigation may be helpful to reduce larval survival. Effectiveness of other management options such as weeding, flooding, ploughing, hand collection of larvae will have to be evaluated under local conditions in field experiments.

Cutworm larvae are parasitised by a wide range of parasitoid wasps, mostly Braconidae and Ichneumonidae, but parasitoid flies are also important. Many of the parasitoids are not host-specific. The application of the egg parasitoid *Trichogramma evanescens* can also reduce populations of cutworms. Predators, entomopathogenic nematodes like *Steinernema* sp. and granulose viruses can also play a role in reducing cutworm damage.

Chemical control is usually not effective, on the contrary, it kills natural enemies of cutworms and other cabbage pests.

Suggested exercises

Exercise	Page	Name	Time required
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.

mon. = monitoring

2.2 Whiteflies - *Bemisia tabaci, Trialeurodes vaporariorum, Aleurodicus dispersus*

Importance

Whiteflies in general damage plants directly by sucking sap from leaves and indirectly by transmitting viruses and producing a sticky secretion known as honeydew, which prevents crops from functioning normally, as well as acting as a substrate for fungal growth (sooty moulds). Virus transmission is not a problem for cabbages, but for other vegetable crops. Chlorotic spots on the surface of leaves are a sign of early infestation. In more serious infestations the entire leaf may turn yellow except around the veins, and then be shed. If severely infested plants are shaken, small white adult whiteflies flutter out and quickly resettle. Larval feeding can cause white streaking on leafy Brassica crops.

The distribution of three major species are given, including the tobacco whitefly *Bemisia tabaci* (Fig. 1), the common whitefly *Trialeurodes vaporariorum* (Fig. 2) and the spiraling whitefly *Aleurodicus dispersus* (Fig. 3).

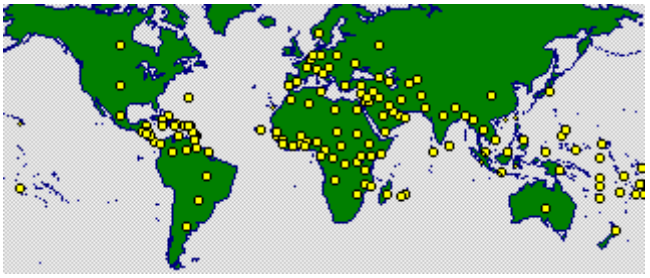


Fig. 1. World distribution of *Bemisia tabaci*

Fig. 2. World distribution of *Trialeurodes vaporariorum*

Fig. 3. World distribution of *Aleurodicus dispersus*

In some crops, whitefly damage can occur through toxins injected in the plant while feeding resulting in silver leafs or irregular ripening of fruit. Although populations in cabbage can be high, infestation seldom leads to severe crop losses.

Description

Eggs
The eggs are whitish-yellow when first laid, gradually turning brown. They are about 0.2 – 0.3 mm long and have a short pedicel or stalk, which is inserted into the host plant during oviposition. The eggs are initially laid singly, along with deposits of waxy secretions on the lower leaf surface, but later in the season they are laid in a circular or a spiraling pattern.

Nymphs
The first nymphal stage ('crawlers') is the only mobile immature stage (0.3 mm long). It is flat, oval and scale-like. During the second nymphal stage (0.5 mm) and the third nymphal stage (0.7 mm) short, waxy rods are formed from pores along the side of the body. During the early pupal stage, which some authors consider as a fourth larval stage, sedentary feeding continues.

Puparium
The fourth nymphal stage, called the puparium, is about 0.7 mm long. The puparium or pupal cases are used for identification purposes. They are flat and oval, about 0.7 mm long. Pupae secrete large amounts of white, cottony, flocculent wax.

Adult
Adults are about 1 mm long or slightly longer, depending on the species. Male and female have slightly different sizes. The body and wings are covered with a powdery, waxy secretion, white to yellowish in colour.

Bemisia tabaci adult (bottom right) beside two *Trialeurodes vaporariorum* adults

B. tabaci adult (body length 1 mm)

Aleurodicus dispersus

Ecology

The eggs are laid in circular groups on the underside of leaves. The eggs hatch after 5-9 days, but this is dependent on host, temperature and humidity. The first nymphal stage is flat, oval, scale-like and mobile. It moves from the egg site to a suitable feeding location on the lower leaf surface. From the second nymphal stage onwards, the legs are lost and the larva becomes sessile or immobile. The first three nymphal stages last 2-4 days each, depending on temperature. True pupation does not occur, but a puparium is formed. Metamorphosis to adult occurs over about 6 days. The adult emerges from the puparium and spreads its wings. Mating begins 12-20 hours after emergence and takes place several times throughout the life of the adult. The lifespan of the female can be up to 60 days. The male lifespan is much shorter, between 9 and 17 days. Each female can lay over 300 eggs in her lifetime. Between 11 and 15 generations can occur within one year. The adults are not very strong fliers but can be transported long distances by the wind.

Whiteflies are mainly problematic during the dry season and disappear rapidly with the onset of the rains.

Pest management

Weeds can be important in harbouring whiteflies between crop plantings and should be removed before planting the crop. Inter-cropping with non-susceptible crops, destruction of crop residues, crop rotation, planting during or shortly after the rainy season, using resistant varieties, mulches can all be explored to reduce whitefly numbers. Monitoring can be done by inspecting leaf and/or by using sticky, yellow traps.

Lacewings and ladybird beetles are major predators, whereas wasps like *Encarsia* and *Eretmocerus* are important parasitoids. Beneficial fungi are *Beauvaria* and *Verticilium*. Fields should be monitored for a wide range of other natural enemies that may occur.

Beneficial insects could be used alongside selective chemicals, such as insect growth regulators. Some insecticides are effective, but most whiteflies have developed resistance to all major groups of pesticides. Because many natural enemies occur in cabbage fields, pesticides should be avoided or kept at a minimum at any time to avoid secondary outbreaks of whitefly.

Suggested exercises

Exercise	Page	Name	Time required
6.3	125	Sampling of arthropods with light traps	½ day + ≤ 1 wk mon.
6.4	127	Sampling of arthropods with sticky board	½ day + ≤ 1 wk mon.
6.35	189	Predation on sucking insects in insect zoo	½ day + ≤ 1 wk mon.
6.36	191	Cage exclusion of natural enemies in field	½ day + ≤ 1 wk mon.
6.37	193	Screen caging in nursery	1 day + 4–8 wks mon.
6.41	201	Parasitism of whitefly	1 - 2 days

mon. = monitoring

2.3 Cabbage aphid - Brevicoryne brassicae

Importance

The cabbage aphid is found in temperate and warm regions throughout the world (Fig.1). Unlike other aphid pests of vegetables, it remains on cruciferous crops throughout its life cycle. It causes severe damage to all cruciferous crops, except for kale and turnip.

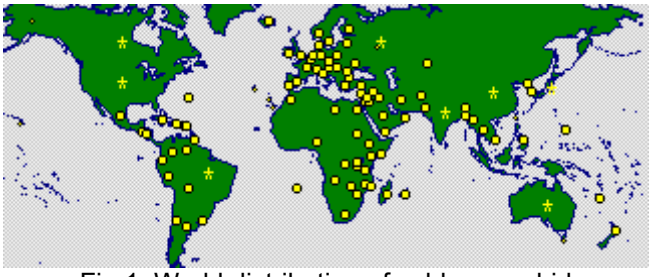


Fig.1. World distribution of cabbage aphid

Cabbage aphids form dense, waxy colonies on plants, preferring young leaves, flowering plant parts and the underside of leaves. The aphids suck the sap from the new growth causing wilting, distortion and mottling of the leaves, and reduced seed set in case of seed crops. Cabbage aphids are not as common on seedlings as are green peach aphids. Populations begin to build up after thinning or transplanting of the cabbages, resulting in stunted growth, plant death and low yields. Cabbage aphids are difficult to remove from plant produce, resulting in economic loss by contamination before processing or marketing.

Cabbage aphids

Description

Eggs
Eggs are only laid in cooler regions. The eggs are black and very small (less than 1 mm).

Nymphs
The live young (nymphs) look like the wingless adults. They are pear-shaped and greenish-white, developing into grey, waxy aggregations. There are four nymphal stages.

Adults
Adult females may be winged or wingless and both forms may appear on the plant. The wingless forms are 1.6-2.6 mm in length, and greyish or dull green, with a dark head and dark markings on the body giving the aphid a striped appearance. The body is covered with a greyish-white, mealy wax, which extends throughout the colony and covers the plant surface. The winged adults are slightly longer, and have almost no wax coating. They have two pairs of wings with brownish veins.


Adult aphids

Ecology

Cabbage aphids reproduce in two ways. In warmer areas, males are not needed. Females give directly birth to live young without mating (asexual reproduction). A single aphid may produce 22-26 young. The young remain in contact with the mother until they are able to survive on their own, causing the formation of compact, waxy aggregations on affected plants. Development from nymph to adult can range from 7-16 days in warmer areas to 40-60 days in cooler areas. When the density of aphids becomes to high, winged females are produced which disperse to other plants.

In more temperate areas, males are produced in the autumn, mating occurs and the females lay eggs. The aphids overwinter in the egg stage. The young develop wings in the spring and disperse to form new colonies.

Generations overlap and all stages of the life cycle may be found throughout the year. Established colonies are made up of individuals of several generations of wingless aphids. The lifespan of the aphid is usually about 28 days and may be shorter at higher temperatures.

Warm, dry weather favours a rapid build-up of aphid colonies.

Pest Management

Good crop hygiene is important for the management of aphids. Local aphid infestations can be hand-picked or pruned out. Surrounding weeds and plants should be checked for aphids before planting and crop residues should be destroyed and fields ploughed after harvest. Mulching can reduce the incidence of cabbage aphid and also helps to control weeds. Rice straw is often used as mulch. Intercropping with non-host crops and the use of 'living mulches' of undersown cover crops are also effective.

Many natural enemies help to keep aphid populations under control. Natural enemies of aphids are not generally host-specific and vary with crop, growth conditions and climate. The most important parasitoid of cabbage aphid worldwide is the parasitic wasp *Diaretiella rapae*, which lays eggs within the aphids. Important predators are syrphid fly maggots (larvae), coccinellid lady beetles, *Chrysoperla* lacewing larvae and spiders. The fungus *Pandora neoaphidis* is another natural enemy of the aphid.

The foliage of affected plants can be sprayed using insecticide soap. The control of other cabbage pests such as Lepidoptera with *Bt* can help aphid control by conserving its natural enemies.

Pesticide sprays are less effective because of the waxy nature of the pest and it’s location on the plants. Insecticides also have adverse effects on natural enemies, which help to keep aphids under control. Some resistance to insecticides has been reported.

Suggested exercises

Exercise	Page	Name	Time required
6.5	129	Sampling for arthropods with water pan trap	½ day + ≤ 1 wk mon.
6.23	165	Mixed cropping examples: cabbage with mustard	Season-long weekly mon.
6.35	189	Predation on sucking insects in insect zoo	½ day + ≤ 1 wk mon.
6.36	191	Cage exclusion of natural enemies in the field	½ day + ≤ 1 wk mon.
6.37	193	Screen caging in nursery	1 day + 4–8 wks mon.
6.40	199	Use of light reflective mulch to manage thrips and/or aphids	Season-long weekly mon.

mon. = monitoring

2.4 Cabbage heart caterpillar - *Crocidolomia pavonana*

Importance

The large cabbage heart caterpillar is an important pest of cabbage, cauliflower, Chinese cabbage, broccoli, kohlrabi, radish and mustard in tropical and subtropical regions (Fig. 1). It is of great economic importance in central and southern India, Indonesia and a few Pacific Island countries. It is found along with diamond back moth (DBM), after which it is the second most important pest of cabbage. A single larva can cause economic loss to cabbage at pre- and post-heading stages.

Fig. 1. Distribution of the large cabbage heart caterpillar

Young larvae feed on the underside of leaf without eating through the upper leaf layer, creating window-like damage patterns (picture below, left). Older larvae completely strip the outer leaves, damage the new growth causing aborted or multiple heads, and cause bore hole damage with frass and faecal contamination in the developing head (picture below, right).

Window-like damage patterns caused by the cabbage heart caterpillar

Bore hole damage

Cluster of eggs

Description

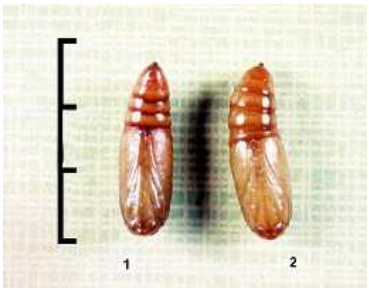
Eggs

The eggs are laid on the underside of young leaves in clusters held together by a glue. The egg mass is arranged like roof tiles in an overlapping manner. It is green on the first day turning reddish-brown at the time of hatching, after 4-5 days.

Larvae

The first stage (instar) of the larvae is slender, greenish-yellow with a dark brown head. The second stage is green, with a brown head. Later stages have yellowish white stripes, three dorsal and two lateral. Mature larvae are 12-16 mm long and up to 2 mm wide.

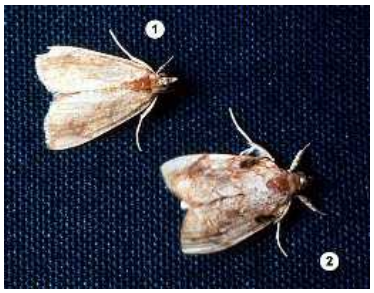
Cluster of eggs with young larvae



Pupae of the cabbage heart caterpillar

Pupae

The pupae are yellowish-green turning dark brown later. Pupation takes place in a silken cocoon, 2-6 cm below the soil surface. The pupa is about 10 mm long and 3 mm wide.



Adults of the cabbage heart caterpillar

Adults

The adults emerge at night. The wingspan of the female is 22-25 mm and of the male 20-25 mm.

Ecology

Females lay 75-300 eggs in a mass on the undersurface of leaves close to the midrib or veins. Smooth leaf surfaces are preferred. The eggs hatch 4-5 days later. There are five larval stages. The early larval stages feed in group, but later stages disperse moving from plant to plant. The larvae feed for 10-18 days, then move down to the soil where they pupate in a silken cocoon in the soil. Pupation lasts 12 days and the adults live for 8 days. The adults are weak fliers. Mating takes place 2 days after emergence. Female moths deposit 2-10 egg clusters of 30-40 eggs each. Generations often overlap. Rainfall is important in reducing numbers and hence the large cabbage heart caterpillar is most common during cool, dry seasons.

The large cabbage heart caterpillar may be found on the crop along with other important cabbage pests such as diamond back moth (DBM) and cabbage webworm. The larvae have different feeding habits to the cabbage webworm, which is a stem borer, and are larger than DBM larvae and produce larger feeding holes. DBM adults have distinctive diamond-shaped markings on the wings.

Pest Management

Indian mustard has been used as a trap crop for control of the cabbage pest complex. For managing the cabbage heart caterpillar, ploughing, removing field debris and removing egg masses and early instars may also be evaluated during field exercises. Cabbages are preferably planted in the rainy season when the populations are low.

There is a low level of natural control of large cabbage heart caterpillar and difficulties exist in mass rearing parasitoids. For this purpose spot spraying *Bacillus thuringiensis* (Bt) may be useful.

Insecticide sprays against the cabbage heart caterpillar are not recommended, as this will cause severe outbreaks of DBM. Besides, once larvae begin boring in the cabbage heads, they are out of reach for contact pesticides. This should also be taken into consideration when spraying Bt.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.19	157	Rainfall as mortality factor	1 day + 4–8 wks mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.21	161	Integrated management of web worm or heart caterpillar on cabbage	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.

mon. = monitoring

2.5 Bollworms - *Helicoverpa* spp.

Importance

The cotton bollworm *Helicoverpa zea*, the tobacco budworm *H. virescens* and the bollworm or corn earworm *H. armigera* are major pests of cotton, maize and vegetable crops including cabbage and kale. The first two species only occur in North, Central and South America, and the Caribbean (Fig. 1), whereas *H. armigera* occurs in the other continents (Fig. 2). The females can lay large numbers of eggs causing rapid population build up. Populations are highest and most damaging late in the growing season.

Fig. 1. World distribution of *H. zea* and *H. virescens*

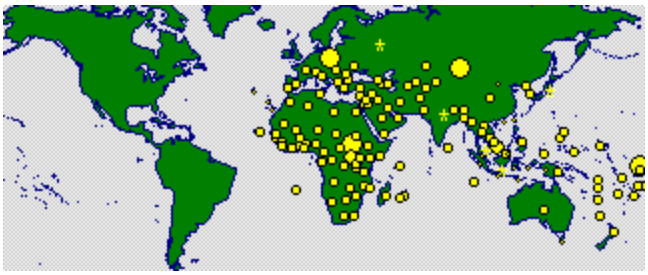


Fig. 2. World distribution of *H. armigera*

The larvae can be seen on the plants, although they are often hidden within flowers, fruits, etc. Damage is usually serious because the larvae can cause visible bore hole damage in cabbage.

Description

Eggs of *Helicoverpa armigera*

Eggs

The eggs are about 0.5 mm in diameter, yellowish-green when first laid, turning red, then grey before hatching. They are stuck singly to the plant. Egg maturity takes 2-3 days.

Larvae

There are usually six larval stages. The first stage is a tiny, grey caterpillar with a black head. The larva varies in colour from green, yellow, pink and red-brown to almost black, and the head is usually pale brown. There are several white, cream or yellow lines running along the body. The final stage larva is 40 mm long.

Helicoverpa armigera caterpillar

H. zea caterpillar

H. zea pupae

Pupae
The caterpillars pupate in a silk-lined cell in the soil, 5-15 cm below the surface. The pupae are light to dark brown, depending on maturity, and about 20 mm long. There are two long, straight spines on the tip.

Adults
The adult is a brown, stout-bodied (15-25 mm long) moth, with a wingspan between 25-45 mm depending on the species. The hindwings are paler than the forewing with a broad dark-brown border.

H. zea adult

H. armigera adult

H. virescens adult

Ecology

A single female usually lays between 1000 and 1500 eggs. The eggs hatch after 2-4 days. The tiny larvae eat the eggshell and then start to feed on the host plant. Larval development usually takes 14-25 days but can take longer under cooler conditions. The larvae feed on most plant parts including stems and leaves. Boring can lead to rotting and leaf drop. The fully fed caterpillar moves down to the ground and burrows to a depth of 10-12 cm, where it rests for a couple of days before pupating. Pupation takes place in response to cold or dry conditions. Pupation takes 10-14 days in the tropics. The adult moths are nocturnal, emerging in the evenings. They are strong flyers and regular seasonal migrants, flying high with the wind currents. The life cycle can be completed in 28-30 days at 25°C in the tropics and there can be up to 10 or 11 generations per year. All stages are found throughout the year if food is available, but development is stopped by drought or cold.

Pest Management

Deep ploughing, discing, altering sowing dates and the use of trap crops can be evaluated in field experiments. Autumn tillage can reduce the success of overwintering pupae in some regions.

Insect parasitoids such as tachinid flies and wasps like *Trichogramma* spp. (Trichogrammatidae) and *Microplitis croceipes* (Ichneumonoidea) can be effective in many areas, although predators feeding on the eggs and young larvae are probably most important. In addition, *Bacillus thuringiensis* (Bt), *Heliothis* nuclear polyhedrosis virus (NPV) and nematodes may be the most successful control method.

Most insecticide applications are targeted at the larval stages, but as these are only really effective when larvae are small, the need to scout for eggs and spray soon afterward is paramount. Young larvae are difficult to find, and older larvae soon burrow into the cabbage heads where they become less accessible to contact insecticides. Pesticide resistance is widespread and has been known for some time. Besides, the negative effects of pesticide use on the wider pest and natural enemy complex has to be considered.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.19	157	Rainfall as mortality factor	1 day + 4–8 wks mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.

mon. = monitoring

2.6 Cabbage webworm - *Hellula undalis*

Importance

The cabbage webworm is a serious pest of cruciferous crops including cabbage, broccoli and cauliflower in warm, lowland regions. In India losses can amount to 30% without control measures. Damage is most severe before the heading stage of cabbage, unlike cabbage heart caterpillars that can affect cabbages at any stage. Nurseries can be destroyed in a few days.

Fig. 1. World distribution of cabbage webworm

The young larvae mine leave midribs, bore stems, and often penetrate the heart of young plants which destroys the terminal bud and prevents heading or causes the development of small, multiple distorted heads. On seedlings, the larvae feed on the growing point and developing leaves while in older plants they feed on leaves and tunnel into the petiole. They spin a silken cocoon while feeding and silk webs may be found on exposed parts of infested plants. The plants wilt and frass can be seen on affected plant parts.

Webworm injury on cabbage

Description

Eggs
The eggs are oval and creamy white when laid. The eggs are laid singly or in groups or chains of two or three on leaves near the bud.

Larvae
There are five larval (caterpillar) stages. The larvae have dark brown or black heads. The body is creamy white to green or grey with dark stripes running lengthwise along the body. Fully-grown larvae are 12-15 mm long.

Pupae
The prepupae are creamy white with faint stripes. Pupae are pale brown with a dark stripe, and shiny. Pupation occurs in a silk cocoon just below the soil surface.

Hellula undalis adult

Adults

The adults are greyish-brown moths with pale hindwings. The forewings have a black spot and are light brown with wavy lines. When resting, the moth is triangular in shape and small (about 1 cm). The wings are 12-13 mm long in males and about 14-15 mm in females. Adults live from 4 to 8 days depending upon temperature.

Ecology

The rate of development and number of generations vary in different geographical regions. The adult can fly over long distances and sometimes migrates to areas outside the normal breeding range. The adults generally emerge in the evening and like other moths are more active at night. Adults seek a mate 3-4 hours after emergence. Egg laying begins within 24 hours after adult emergence and continues for 3-10 days. The number of eggs laid varies from 28 to 214. The egg stage lasts 2-5 days, the larva 6-18 days, the prepupa 1-3 days and the pupa 4-20 days. The adults are not often seen in cabbage fields and damage may not be detected until stunted or deformed plants appear. Attack is mainly serious during and directly after the rainy season when the first true leaves develop.

Pest Management

The cabbage webworm often occurs in the same area as the diamond back moth (DBM) and other cabbage pests and this affects the management measures that can be used. Crops should be inspected for larvae during the nursery stage and on young transplants.

Weeding, clean cultivation, hand collection of larvae or eggs and removal of infested leaves will have to be evaluated under local conditions in field experiments.

Insecticides kill natural enemies and create new pest problems. If *Bt* is applied, this should be done before larvae are protected by their web or before they have moved into the leaves, heads or stems.

Suggested exercises

Exercise	Page	Name	Time required
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.23	165	Mixed cropping example: cabbage with mustard	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.

mon. = monitoring

2.7 Leafminers - *Liriomyza* spp.

Importance

The serpentine leafminer *Liriomyza brassicae* is a cosmopolitan pest of wild and cultivated cruciferous plants (Fig. 1), whereas the American serpentine leafminer *L. trifolii* and the vegetable leafminer *L. sativae* occur also cosmopolitan (Figs. 2 and 3), but on a wider range of vegetable crops.

Fig. 1. World distribution of serpentine leafminer

Fig. 2. World distribution of American serpentine leafminer

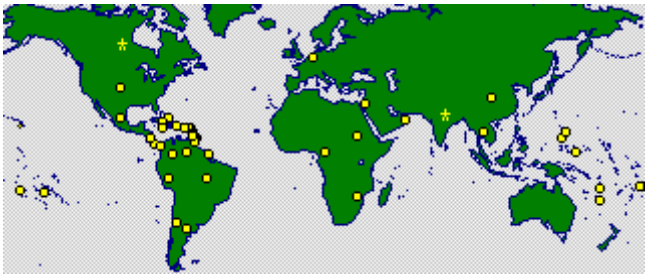


Fig. 3. World distribution of vegetable leafminer

Young plants and seedlings are most susceptible and may be killed or weakened by large numbers of larvae. The larvae feed on the leaves creating, whitish/greenish tunnels or mines, which can affect plant growth, make the product unmarketable and leave the plant open to infection. The mines are more winding in case of the serpentine leafminer. The frass of *L. trifolii* is distinctive in being deposited in black strips alternately at either side of the mine (like *L. sativae*), but becomes more granular towards the end of the mine (unlike *L. sativae*). These mines may be the first sign of damage. Entire leaves may become mined when the population of larvae is high. Most mining damage to mature plants is done on the outside leaves, which are rarely eaten by people and do not affect the growth of the plant.

Description

Eggs
The eggs are inserted just below the leaf surface. Many eggs can be laid on a leaf, usually singly. Freshly laid eggs are creamy white and oval. They are small (0.25 mm by 0.1mm) and hatch within 2-5 days.


Leaf mine of *Liriomyza sativae* on cabbage

Larvae
The larvae are transparent when first hatched, becoming yellow-orange in later stages. They are up to 3-4 mm long. There are three larval stages. The rate of development depends on temperature and the host plant. The larvae feed directly under either the upper or lower surface of the leaf.

Pupae
The larvae emerge from the mines to pupate in the soil beneath the plant. Development of the pupa varies with season and temperature. The pupa is yellow-brown and segmented and does not cause any damage. The adult emerges after 7-14 days between 20 and 30°C.

Adult
The adult is a small fly with black and yellow colouring. It is very small, only 1-2 mm long. Adults live for 10-20 days depending on environmental conditions.


Liriomyza trifolii


L. trifolii male

Ecology

Up to 24 generations can occur during the year, the life cycle taking less than three weeks in warm weather. Adults usually emerge before mid-day and males usually emerge before females. Mating takes place 24 hours after emergence. The female fly punctures the leaf to feed and to lay eggs. These punctures may be visible to the naked eye. Male flies cannot puncture the leaves but will feed from the punctures made by female flies. Both males and females feed on the nectar from flowers. The flies are not very active fliers. They walk over the leaves and fly to the nearest leaves. The adults live for between 15 and 30 days.

Pest management

Good crop hygiene is important in managing leafminer damage. Damaged leaves can be picked and destroyed, infected plant material should be cleared and burned, plant material removed after harvest and the soil prepared before harvest. Flooding then hoeing the soil can expose the buried pupae, which will then be destroyed by exposure to sunlight. Examination of seedlings before planting and avoiding planting next to infected fields can prevent the introduction of the pest.

Natural enemies, especially parasitic wasps, are important in limiting leafminer damage. Nematodes such as *Steinernema carpocapsae* can also reduce leafmining pests.

Insecticide application of pesticides on mature plants is of little value because of the hidden nature of the pest and may result in chemical residues on the crop. Care must also be taken to avoid destroying natural enemies of this and other cabbage pests by refraining from pesticide use early in the season.

Suggested exercises

Exercise	Page	Name	Time required
6.42	203	Parasitism of leaf miners	½ - 1 day + 2-3 wks mon.

mon. = monitoring

2.8 Cabbage moth – *Mamestra brassicae*

Importance

The cabbage moth is found from Europe to Japan and subtropical Asia. It is a serious pest of cruciferous and other vegetable crops. Up to 80% losses have been reported on cabbage. It is a sporadic pest in more northern areas of its distribution.

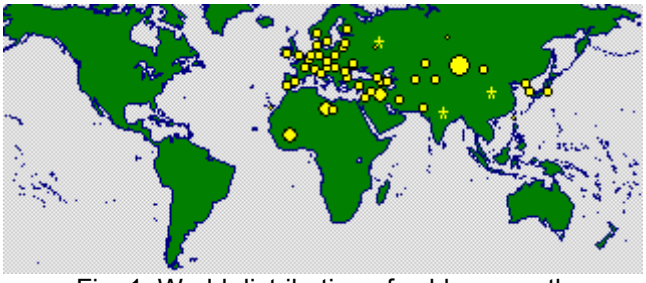


Fig. 1. World distribution of cabbage moth

The small larvae feed on the underside of the external leaves making holes. Severe infestations may skeletonize the leaves, leaving only the veins and can sometimes destroy small plants. Older larvae tunnel into the heart of the plants. Most crop losses are the result of boring and contamination rather than the loss of leaf tissue. Minor infestations by older larvae can destroy the marketable product.

Description

Eggs
The eggs are relatively small, hemispherical and ribbed. They are whitish when laid becoming purplish-brown, then greyish-black a few hours before hatching. The eggs are laid in regular batches of up to 70-80 eggs, mainly on the undersides of leaves.

Mamestra brassicae caterpillars

Larvae
There are six larval stages (instars). The first and second stages are 3-10 mm long, greenish and almost translucent. The first stage larva has a black head but this becomes light brown in later stages. By the third stage, the larvae are pale green with yellowish intersegmental bands. The final stage larvae are mainly brownish-green to blackish-green. Fully-grown larvae are up to 5 cm long.

Pupae
The pupae are 17-22 mm long, reddish-brown and glossy. Pupation takes place in thin cocoons in the soil.

Adults
The adult moths have a wingspan of 34-50 mm. The forewings are mottled and grey-brown, brown or blackish-brown, with reddish-brown scaling. The eyes are hairy.

Ecology

The adult moths emerge from pupae in the soil. Shortly after emergence the moths mate and the females lay their eggs in batches of up to 70-80 eggs, mainly on the underside of leaves. The eggs normally hatch in 6-14 days. The larvae spread all over the cabbage plant within hours of hatching and disperse to new plants throughout the larval stages. The first few larval stages feed mainly on the external leaves. From the fifth larval stage they move into the heart of the plant. Late stages often hide in the soil during the daytime and enter the plants to feed at night. Larval development usually takes 4-7 weeks. Mature larvae leave the plants to pupate in thin cocoons in the soil at a depth of 3-5 cm. The moth is nocturnal with emergence from pupae, flight, mating, egg laying and feeding mainly taking place at night.

Pest management

In temperate regions, early planting of cabbage can prevent damage by allowing the heads to form before the mass emergence of larvae. Summer harrowing and ploughing after harvest and in autumn may also be effective. The use of nets in the nursery can also prevent damage as long as there are no pupae in the soil. Intercropping and the use of cabbage varieties resistant to cabbage moth should be explored. Red cabbage is less infested with larvae than white or Savoy cabbage.

Care must be taken to preserve and encourage the build up of the wide range of natural enemies that may be important in regulating numbers of cabbage moth. In some countries the egg parasitoid *Trichogramma* is commercially available, as well as products of *B. thuringiensis* (Bt) and baculoviruses. The use of entomopathogenic fungi, along with other management practices, should be explored in the field through appropriate exercises.

The botanical neem seed extract may be effective. However, as with other caterpillars, management treatments must be applied when the larvae are small and vulnerable, before they bore into the heart of the plant and are protected.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.

mon. = monitoring

2.9 Green peach aphid - *Myzus persica*

Importance

Green peach aphids have a worldwide distribution (Fig. 1). They attack many crops including cruciferous plants. The aphid adults and nymphs suck the sap from plants causing feeding damage. They also transmit virus diseases.

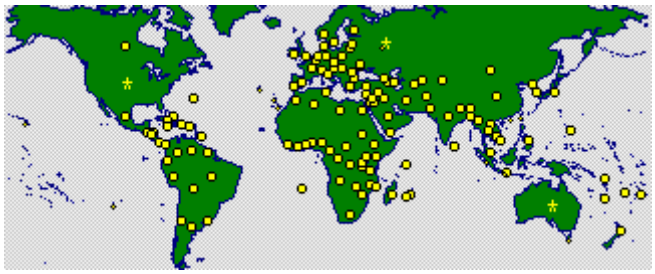


Fig. 1. Worldwide distribution of green peach aphid

The aphids are common on seedlings and young plants, which may be stunted if the aphid population is high. They also attack the lower leaves of older plants but are rarely found in the heads of cruciferous crops. Smaller populations may be tolerated by the removal of outer leaves. Green peach aphids rarely cause damage in older cabbage.

Description

Eggs
In warmer areas, females give directly birth to live young without mating (asexual production). In temperate regions, the aphids overwinter in the egg stage. The eggs are shiny and black.

Winged and wingless forms of peach aphids on cabbage leaf

Nymphs
The immature stage (nymph) of the aphid is pale yellowish-green with dark lines. Adult females give birth to around 50 nymphs.

Adults
Both winged and wingless forms occur. The wingless adults are oval, 1-2 mm long and vary in colour from green to pale yellow. Winged forms are green with black or dark brown markings. The green peach aphid disperses to summer hosts in the winged form. A hand lens or microscope is needed to look at more detailed features.

Ecology

The main host of the green peach aphid (peach) does not grow in the tropics and subtropics and so there is no swapping between hosts in these areas and active stages of the aphid survive throughout the year. In more temperate areas, the aphid moves between the main host, peach, in winter and summer hosts. Wingless forms develop on summer hosts until daylength and temperature fall, then they move back to peach.

Populations of the green peach aphid are highest during periods of rainfall and lowest during hot, dry weather.

Pest Management

Monitoring is important in field crops. It is also important to remove crop residues and weed hosts before planting as the aphid can develop on both cultivated crops and wild plants. Early sowing and the use of certified seed could be tested as well as those methods used to reduce cabbage aphids.

Green peach aphids are attacked by a number of natural enemies, which vary with crop, growth conditions and climate.

Insecticides have had limited success in controlling green peach aphid and resistance to a range of insecticides has developed worldwide. Neem is effective against green peach aphid. The waxiness of *Brassica* crops decreases aphid colonization compared to other crops.

Suggested exercises

Exercise	Page	Name	Time required
6.5	129	Sampling for arthropods with water pan trap	½ day + ≤ 1 wk mon.
6.23	165	Mixed cropping examples: cabbage with mustard	Season-long weekly mon.
6.35	189	Predation on sucking insects in insect zoo	½ day + ≤ 1 wk mon.
6.36	191	Cage exclusion of natural enemies in the field	½ day + ≤ 1 wk mon.
6.37	193	Screen caging in nursery	1 day + 4–8 wks mon.
6.40	199	Use of light reflective mulch to manage thrips and/or aphids	Season-long weekly mon.

mon. = monitoring

2.10 Flea beetles - *Phyllotreta* spp.

Importance

Flea beetles occur worldwide. They are small, shiny, hard beetles that jump like fleas when disturbed. The crucifere flea beetle *Phyllotreta cruciferae* is not common in the Far East but is the most common flea beetle in India (Fig. 1). The cabbage flea beetle *P. striolata* is also important in several other Asian countries (Fig. 2). Flea beetles are a minor pest in Western Europe but are an important pest of crucifers in Eastern Europe. They are the main pests of cruciferous crops in the north of North America.

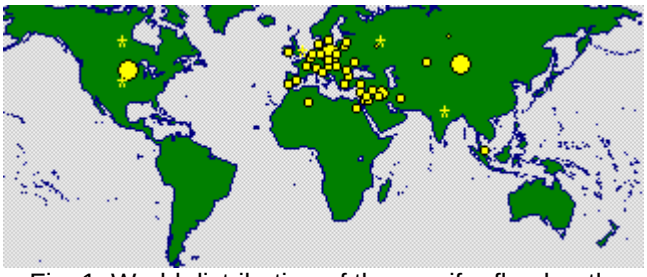


Fig. 1. World distribution of the crucifer flea beetle

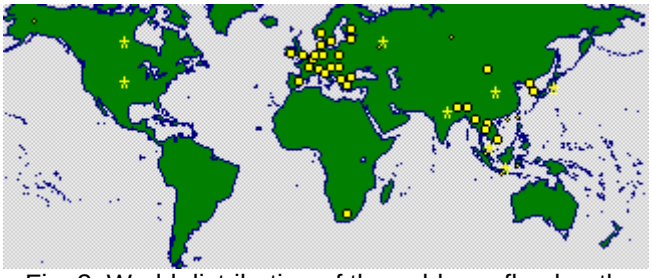


Fig. 2. World distribution of the cabbage flea beetle

These flea beetles feed mainly only on cruciferous crops and other plant families known to contain mustard oils. They can also live on cotton and cereals. Seedlings are most susceptible to damage, although all stages of the crop are attacked. They scrape leaf tissues causing characteristic perforations, or feed on the roots.

Description

Severe leaf damage by flea beetles

Eggs
The eggs are ovoid to elliptical, creamy-yellow, and 0.3 mm by 0.15 mm. They are laid singly or in small groups in the soil around the base of plants.

Larvae
There are three larval stages (instars). The last larval stage is 3-5 mm long, whitish, slender and cylindrical, with a brown head and very short legs. The larvae feed on roots. The prepupa is shorter and thicker than the feeding form.

Pupae
The pupae are about 2.5 mm long, whitish-yellow darkening to black just before emergence as adults.

Adults
Adult flea beetles are small, elliptical, leaf-feeding beetles, 2-3 mm in length. They vary in colour from shiny black to metallic blue-black to blackish-bronze. Some flea beetles have their back in one colour, while others have two longitudinal yellow bands on their back. When disturbed the beetles jump like fleas.


Crucifere flea beetles on a cotyledon of oilseed rape


Cabbage flea beetles

Ecology

In tropical lowlands flea beetles reproduce continuously. In colder climates adult beetles spend the winter in leaf litter on the soil surface or in cracks in the soil, often under trees or shrubs. In the spring, the adults walk or fly from overwintering sites to feed on cruciferous weeds and plants, moving to cruciferous crops once the seedlings emerge. They can travel long distances on prevailing winds, often in group, and devastate a crop, especially in hot, dry conditions. Rainfall has a negative effect on flea beetles.

After mating the adult females lay eggs at the base of the host plant, singly or in small clumps of up to 45 at a depth of 2-3 cm in the soil. The larvae emerge after about 2 weeks. They feed on the roots and subterranean stems and develop through three larval stages in 3-4 weeks. On cabbage they are found at depths of up to 12 cm in the soil. Towards the end of the last larval stage, the larvae pupate in the ground, in the soil around the host plants. The pupal stage lasts 7 days to 4 weeks. The entire cycle from egg to adult takes about 6-8 weeks.

Pest management

A number of cultural methods like weeding in and around cabbage fields, removing or ploughing plant residues deep into the soil, and practices that enhance early germination, and increase seedling vigour and growth, can reduce damage caused by flea beetles. Covering seedlings reduces feeding and promotes crop maturity.

In areas where crucifer flea beetles are a pest, natural enemies of the beetle are not common and are not effective in control, except for generalist predators like spiders. Entomopathogenic nematodes like *Steinernema carpocapsae* could be used.
Seed treatment with insecticides and fungicides is an effective method for protecting the crop until the first true leaf strage. The application of insecticidal soaps at the cotyledon stage may be useful. Seedlings should be checked twice weekly for flea beetle damage until the plants are well established. At later stages, flea beetles are generally not harmful anymore.

Suggested exercises

Exercise	Page	Name	Time required
6.14	147	Plant compensation study	Season-long weekly mon.
6.22	163	Use of screen in the nursery	1 day + 4–8 wks mon.

mon. = monitoring

2.11 Cabbage white butterflies - *Pieris* spp.

Importance

The large white cabbage butterfly *Pieris brassicae* and the imported cabbage worm or small white butterfly *Pieris rapae* are migratory pests that can be found anywhere. It prefers cultivated areas, particularly areas where cruciferous crops are grown. It is a major pest of cabbage, mainly in the cooler regions or highlands.

Fig. 1. World distribution of the large white cabbage butterfly

Fig. 2. World distribution of the imported cabbage worm

Large populations can build up, especially under conditions of high temperatures, long exposure to sunlight, and low relative humidity and rainfall. The larvae attack the leaves. They strip the growing shoots and even whole plants. When cabbage is severely infested, the plants are completely stripped leaving only the major leaf veins. The first indication of infestation is holes in the young leaves and large groups of larvae resting on the underside of the leaves. Older larvae usually rest on the upper surface of the leaf. Adults flying around a crop mean that eggs are being laid and that the crop will be damaged.

Description

Eggs
The eggs are bright yellow to light yellow, bottle-shaped, 1 to 1.4 mm high and ribbed. They are laid upright in clusters of 40-100 on the underside of a cruciferous plant (large white cabbage butterfly), or singly on the underside of a leaf of any plant in the field (imported cabbage worm). The eggs change to orange just before hatching.

Pieris brassicae eggs

Pieris rapae eggs

Larvae

The larvae have five pairs of prolegs. All later-stage larvae have yellow lines running along the length of their body and produce a thick green liquid to deter predators and parasitoids. The newly-emerged larvae of *P. brassicae* are yellow with shiny, black heads. Later stages are yellowish-green and have a wrinkled texture. Fully-fed larvae are 45 mm long and are covered with fine black hairs. The mature larvae of *P. rapae* are only about 3 cm long, their head and body are velvety green with short hairs. There are numerous black, and occasional white, minute raised spots from which arise short translucent hairs. Segments have one or two yellow lateral spots.

Pieris brassicae larvae

Pieris rapae larva

Pieris rapae larva

Pupae

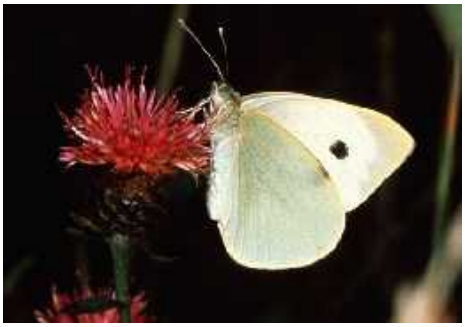
The pupae are 20 mm long and either pale green or greyish-white with black and yellow markings. They are found on walls, fences, tree trunks and stones or under roofs and branches. When attached to the food plant the colour of the pupa is usually green, but pupae attached to other objects tend to assume the colour of the background and they are often grey or pink.

Pieris brassicae pupa

Pieris rapae pupa

Adults

The wingspan of the adult butterfly is 55-70 mm (*P. brassicae*) or 40-60 mm (*P. rapae*). The upper side of the wings is usually a bright white with a clear black tip to the forewing. The female also has two black spots on the wing. The undersides of the wings are pale yellow with grey, but the centre and base of the forewings is white. In the female the black dots on the forewings also appear on the underside.



Pieris brassicae adult

Pieris rapae adult

Ecology

The cabbage white butterflies do not live in permanent colonies but breed wherever they find suitable conditions. When conditions are favourable, huge numbers are produced, resulting in strong migrations. The females usually begin laying eggs within a day or so after emergence. After 4-14 days, the eggs hatch and the larvae feed and develop through five instars in 10-30 days. The larvae live in groups (*P. brassicae*) or solitary (*P. rapae*) for most of their life. When not feeding, the larvae lie along the ribs of the leaves. When fully grown they leave the host to find somewhere to pupate on or under a protective surface above the ground (*P. brassicae*) or larvae fasten themselves to the lower leaf surfaces by silk bands (*P. rapae*). The pupal stage lasts for 7-15 days.

Pest Management

Field sanitation (removal of crop residues), the use of netting to cover the crop, or hand collection of egg masses and young larvae may be effective as a management practice and should be evaluated in field exercises.

Populations of cabbage caterpillar vary due to high levels of parasitism. Some important natural enemies such as *Cotesia* or *Trichogramma* can destroy almost 100% of the early stages of the pest. Other parasitoids, predators and pathogens like *Bacillus thuringiensis* (Bt) or the fungus *Metarhizium* sp. should also be evaluated. Birds and ground beetles can be important predators.

Botanical insecticides such as neem may be safer to natural enemies than most pesticides.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.23	165	Mixed cropping example: cabbage with mustard	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.

mon. = monitoring

2.12 Diamondback moth – *Plutella xylostella*

Importance

The diamondback moth (DBM) is a major pest throughout the world (Fig. 1). It attacks a wide range of wild and cultivated cruciferous crops such as cabbages, watercress, mustard, kale, turnip and broccoli. The pest is most damaging during the seedling and early transplanting stage, insect larvae feeding on all above-ground portions of the plant. Destruction of the main buds of seedlings by DBM larvae may result in plants with multiple undersized heads. However, when farmers remove all of the new shoots but one to develop a new head, this may still result in a good crop (plant compensation).

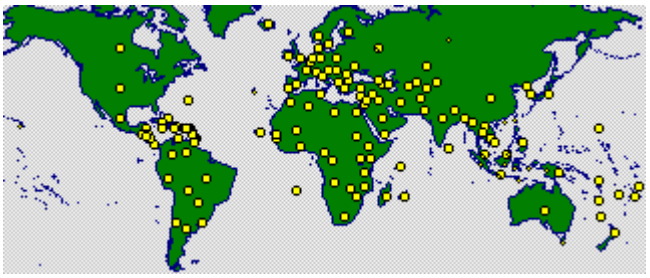


Fig. 1. Distribution of DBM in the world.

Total crop failure may occur where effective management measures are not taken. Pesticide resistance has exacerbated problems with DBM and despite increasing cost of production due to higher pesticide use, crop losses are increasing. The control of this pest is estimated to cost the world economy about US$1 billion every year.

Description

Diamondback moth eggs

Eggs

The small (0.44 x 0.26 mm) white-yellowish eggs can readily be seen in the field using a hand lens. They are laid either individually or in small groups near the leaf veins. The time before larvae emerge (incubation period) depends upon temperature and can take 3 to 8 days.

Larvae

There are four different stages (instars) of larvae or caterpillars. The first instar caterpillars crawl to the underside of the leaf and then mine into the leaf tissue. After the first instar, the caterpillars emerge from the leaf and usually feed on the lower leaf surface causing holes in the leaves. With heavy infestation, the caterpillars skeletonize the leaves and only the midribs and veins of leaves remain. Fully grown caterpillars are green and up to 13 mm long.

Diamondback moth caterpillar


Diamondback moth pupa

Pupae
The fully grown larvae spin a cocoon around themselves to pupate. These cocoons are often fastened to the plant parts (mostly leaves) and frequently hidden in crevices near the bud. The pupal stage lasts for about 5-10 days after which the adult emerge.


Diamondback moth adult

Adult
Mating begins at dusk on the day of emergence and oviposition begins shortly after dusk. The average longevity of female and male is about 2 weeks. Each female lays between 50 and 400 eggs.

Ecology

DBM can live and reproduce under a wide range of climatic conditions. Generally, the higher the temperatures, the shorter the life cycle. Up to 20 generations per year have been recorded in the tropics, but only four generations in cold places. The rate of development of larvae may last from 6 days to about 3 weeks depending on the temperature regime.

Despite breeding throughout the year in tropical conditions, the DBM, along with many other leaf-feeding insects, infests cruciferous crops mainly during the cool and dry season. Rainfall, along with other limiting factors (e.g. food scarcity, natural enemies) reduces its population density.

Pest Management


Diamondback moth pheromone trap

Pheromone traps for monitoring of DBM exist.

Several management practices such as clean cultivation, intercropping, trap cropping and conservation of natural enemies should be explored in the field.

Important natural enemies are parasitoid wasps like *Diadegma* spp., *Cotesia* sp. and *Diadromus* sp. Pictures of these are given in the chapter on parasitoids. For natural enemies to be successful, most important is to avoid using chemical pesticides.

Application of *Bacillus thuringiensis* (Bt) and botanical insecticides such as neem should be evaluated in the field.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.13	145	Diamondback moth injury symptoms on cabbage	1 day + 4–8 wks mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.15	149	Assessment of impact of ground-dwelling predators	1 day + 4–8 wks mon.
6.17	153	Parasitisation on diamondback moth of cabbage	½ day + ≤ 1 wk mon.
6.18	155	Effect of parasitisation on feeding behaviour of diamondback moth	½ day + ≤ 1 wk mon.
6.19	157	Rainfall as mortality factor	1 day + 4–8 wks mon.
6.22	163	Use of screen in the nursery	Field study
6.23	165	Mixed cropping example: cabbage with mustard	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.
6.44	207	Role play on insecticide resistance	½ day or less

mon. = monitoring

2.13 Armyworms - *Spodoptera* spp.

Importance

Armyworms attack a wide range of crops and can be found on almost any plant as they migrate in search of new sources of food. Infestations vary from year to year and can occur suddenly with large numbers appearing rapidly. The beet or lesser armyworm *Spodoptera exigua* attacks most kinds of field crops including cabbages and other vegetable crops. It is a sub-tropical and tropical species, which is adapted to warm climates (Fig. 1). *S. litura* and *S. littoralis* have only recently been identified as different species, and occur in different regions (Figs. 2 and 3).

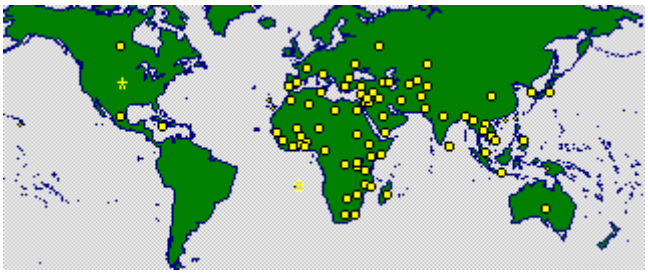


Fig. 1. World distribution of *S. exigua*

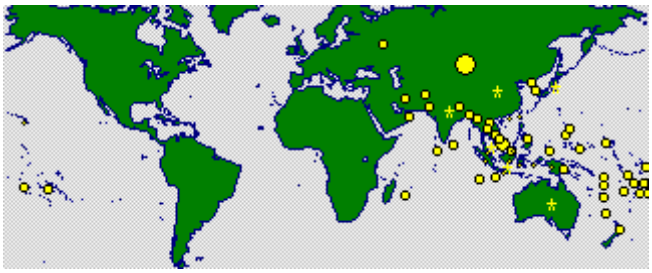


Fig. 2. World distribution of *S. litura*

Fig. 3. World distribution of *S. littoralis*

Damage is generally first observed on plants at the field edges. The first larval stages cause little feeding damage but later stages can consume up to 85% of all the foliage eaten. The larvae feed on the lower surface of the leaf, eating the leaf tissue but not the upper surface or the large veins. Larger larvae make irregular holes in the leaves and fully-grown larvae strip the leaves and destroy the plants, leaving only the major veins. In severe infestations, the larvae will also eat the veins and other plant parts leaving only stubble.

Description

S. litura egg masses

Eggs

The eggs are very small (0.7 mm in diameter), round and pale greenish or pinkish. They are laid in masses of about 50-150 eggs in layers on or under the leaf surface. Egg masses measure 4-7 mm in diameter and appear golden brown to grey-pink because they are covered with body scales of the female moth which make them look hairy.

Larvae

There are five or six larval stages. The newly hatched larvae are green, becoming light green to dark brown, although the colour varies depending on the food ingested. Mature larvae have a smooth appearance. The middle of the back is olive green to almost black with light green to yellow stripes running along each side of the body. The final larval stage is 2.5 - 4 cm long, those of *S. exigua* being smallest.

S. exigua larva

S. litura larva

S. littoralis larva

Pupae

The pupae are up to1.5 cm long, shiny brown and found within an earthen shell.

Adults

S. exigua is smaller than the other two species. The adults are mottled grey moths of about 1.2 to 2 cm long with a wingspan of 2.5 to 4 cm. The forewings are light grey with a small, round, light orange spot in the middle. The hindwings are white to straw coloured with dark brown veins and edges.

S. exigua adult

S. litura adult

S. littoralis adult

Ecology

The female moths lay eggs in masses, mainly on the lower surface of the lower leaves. Each female can lay between 500 and 1500 eggs, depending on growth conditions and generations. The eggs hatch in 2-5 days and the emerging tiny caterpillars begin feeding on the underside of young leaves. The first two larval stages feed in groups and cause little damage. The larger larvae migrate in order to

feed solitary, leaving only one or two larvae per plant. The larvae feed on leaves during the night and on cloudy days, and hide under crop debris during sunny periods. Larger larvae are either nocturnal or enter the armyworm phase, where they swarm and disperse to new food sources. The rate of larval development is dependent on diet and temperature and is highest at 28°C. It generally takes between 15-21 days. Pupation takes place in a cocoon in the soil, and development takes 6-12 days. Adults emerge at night and often fly for long distances before settling to lay eggs. Adults live for 8-11 days. The short generation time (from egg to adult stage) of about 25 days means that several generations can be completed in a cropping cycle at 24-28°C. Breeding can be continuous in the tropics with four to six generations per year. In northern regions, only one or two generations develop. In these areas, the beet armyworm will overwinter in warmer regions of the Mediterranean, North America and Africa, returning to invade the cooler, northern regions when temperatures permit.

Pest Management

Flooding, ploughing, burning of crop stubble and removing of weeds, or using trap crops can help as preventive measures, whereas hand collection of larvae and egg masses can be evaluated once armyworms are present in the field.

Natural enemies usually prevent the development of economically damaging infestations. Armyworms are attacked by a large number of generalist natural enemies and natural mortality can be as high as 98.6%. The parasitic wasp *Hyposoter* sp. attacks the larvae, and viruses and bacterial diseases may also provide natural control. The beet armyworm has been controlled by *Telenomus remus* in the Americas. This parasitoid has also been effective against bollworms and cutworms.

Biological pesticides, such as *Bacillus thuringiensis* (Bt) and nuclear polyhedrosis virus (NPV) can be tested for use against armyworm.

Insecticide resistance to certain chemicals has been reported. Intensive early season application of broad-spectrum insecticides can increase armyworm problems by destroying natural enemies.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.

mon. = monitoring

2.14 Thrips – *Thrips* spp.

Importance

Major thrips on cabbages are the cabbage thrips *Thrips angusticeps*, tobacco thrips *T. tabaci* and melon thrips *T. palmi*. They have a different geographical distribution (Figs 1, 2 and 3), and their economic damage varies. Many cultivated crops are attacked including cruciferous plants such as cabbage and broccoli.

Fig. 1. World distribution of cabbage thrips

Fig. 2. World distribution of tobacco thrips

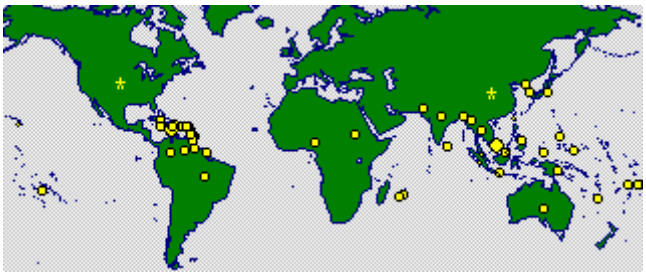


Fig. 3. World distribution of melon thrips

Most forms of damage may be mainly cosmetic. However, seedlings are more vulnerable than established plants and if a high number of thrips are present, plants may become distorted, stunted and sometimes killed. Typical thrips damage on leaves and stems is known as 'silvering' and is produced by feeding. These damaged areas can then turn yellow or brown or necrotic (see pictures below).

Thrips damage on cabbage

Thrips damage on leek

Description

Eggs

The eggs are too small to be visible to the naked eye. They are inserted into the plant. They are white to translucent, kidney-shaped and about 0.3 mm long by 0.1 mm wide.

Thrips palmi

Larvae

There are two larval stages. Larvae are yellowish-white and about 0.5-1.2 mm long. There are two larval stages (instars). A microscope is needed to examine detailed features of the larvae. Larvae may be predatory on small arthropods, mite eggs and small mites.

Pupae

There are two pupal stages. These two stages differ in development from the larvae by the presence of wing-sheaths. The pupae are whitish, about 1-1.5 mm long, inactive and occur in the soil, and so are rarely found.

Adults

Adults are pale yellow to brown and about 1-1.5 mm long. Both males and females have long-winged and short-winged forms. The long wings are greyish-brown and pale at the base. Short wings are pale. Specimens must be viewed under a microscope to examine detailed features.

Thrips tabaci

Thrips palmi

Ecology

After mating the females fly to new crops to feed on the leaves, stems and growing points. The females lay eggs 10-15 days after emerging from pupa in the soil. About 1-3 eggs are inserted just below the plant surface. The eggs take 3-12 days to hatch. Development takes longer at lower temperatures. The larvae feed on the leaves and stem of the plant. They suck the contents of the tissues but tend to hide within small spaces or between leaves and so are not obvious. When fully grown, the larvae drop to the soil and penetrate deep down along fine cracks. The larva turns into a prepupa and then to a pupa. The complete life cycle may take as little as 11 days.

Pest management

Avoiding thrips damage could be explored by constructing mechanical barriers such as screen cages over seedlings and young plants.

Fields should be evaluated for parasitoid wasps, parasitic nematodes, fungal diseases and predators including mites, lacewings and bugs like *Orius* spp. Practices that stimulate the presence and activity of these natural enemies should be explored locally.

Crop rotation can be an effective control measure in some cases although most thrips feed on a wide variety of plants.

Insecticide treatment is not always worthwhile due to escape and possible resistance.

Suggested exercises

Exercise	Page	Name	Time required
6.4	127	Sampling of arthropods with sticky board	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.35	189	Predation on sucking insects in insect zoo	½ day + ≤ 1 wk mon.
6.37	193	Screen caging in nursery	1 day + 4–8 wks mon.
6.38	195	Thrips feeding symptom development	1 day + 4–8 wks mon.
6.39	197	Rainfall as thrips' mortality factor	1 day + 4–8 wks mon.
6.40	199	Use of light reflective mulch to manage thrips and/or aphids	Season-long weekly mon.

mon. = monitoring

2.15 Cabbage looper - *Trichoplusia ni*

Importance

The cabbage looper is a very destructive pest of a wide range of plants but it prefers cultivated cruciferous crops. It is a widely distributed pest (Fig. 1). The adult moth is capable of migrating long distances.

Fig. 1. World distribution of cabbage looper

The cabbage looper causes severe losses in yield and quality, especially under dry conditions. The larvae feed on leaves making large, irregular holes, even skeletonizing leaves. Later stages bore into the heads of cabbage and some other crops. Most injury occurs after heading. Seedlings are sometimes damaged and high populations of the larvae can kill seedlings or slow down growth, affecting the mature crop. Infestations can make cabbage heads contaminated with frass and unmarketable at the end of the season.

Description

Eggs
The eggs are about 0.5 mm, round or dome-shaped with ridges. They are pearly or silvery white and are laid singly, usually on the underside of leaves.

Cabbage looper eggs

Cabbage looper larva

Larvae
There are five larval stages. The first stage is white and almost clear, with a black head. Later stages are smooth and green with four white stripes. The larva has three sets of legs near the head and three sets of prolegs near its rear. As it moves, the middle section of the body becomes arched, giving it the name of looper.

Pupae
The last larval stage spins a cocoon and creates a pupa inside. The pupa is yellow-green, turning brown as it ages, and is about 2 cm long.


Cabbage looper pupa


Cabbage looper adult

Adult
The adult is about 2.5 cm long and a mottled, greyish-brown. The front wings have two small silvery spots near the centre of the wing. The hind wings are pale brown.

Ecology

In some areas, cabbage loopers overwinter as pupae attached to leaves that have fallen to the ground. The adults emerge in the spring. They are active at night but can be found resting on crops during the day. Adult females lay up to 350 eggs, singly and mainly on the lower surfaces of the leaves. The larvae hatch from the eggs 3-10 days later and begin feeding on leaves. They eat hungrily for 2-4 weeks then spin a cocoon and pupate, usually in leaf litter and crop debris. The next generation of moths will emerge within two weeks. There are 3-5 generations of cabbage looper per year depending on the region and climate.

Pest management

There are pheromones available for monitoring loopers.

Clean cultivation should be evaluated as a preventive measurement against loopers, as against other caterpillar pests.

Intervention is not often needed because of the abundance of natural enemies, so regular monitoring of natural enemies is also important. Cabbage loopers are attacked by a large number of parasitoids and egg parasitoids of the Trichogrammatidae may be particularly useful. *Cotesia* spp. and nuclear polyhedrosis virus (NPV) have been used to control cabbage looper on cabbage in Trinidad.

Applications of biopesticides such as *Bacillus thuringiensis* and the beneficial fungus *Beauveria bassiana* can be useful in addition to indigenous biological control.

For reasons of insecticide resistance and increased problems of other caterpillars like the diamondback moth, insecticides should be avoided.

Suggested exercises

Exercise	Page	Name	Time required
6.12	143	Life cycle of caterpillar pests	½ day + ≤ 1 wk mon.
6.14	147	Plant compensation study	Season-long weekly mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.19	157	Rainfall as mortality factor	1 day + 4–8 wks mon.
6.20	159	Hand picking of eggs and caterpillars	Season-long weekly mon.
6.24	167	Comparison of biological and chemical pesticides used in caterpillar control	½ day + ≤ 1 wk mon.
6.25	169	Assessment of viability of B.t.	½ day + ≤ 1 wk mon.
6.26	171	Inhibition of larval feeding by B.t.	½ day + ≤ 1 wk mon.
6.27	173	Sensitivity of B.t. to sunlight	½ day + ≤ 1 wk mon.
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.

mon. = monitoring

3. Disease Fact Sheets

3.1 Alternaria leafspot - *Alternaria brassicae, A. brassicicola*

Alternaria leafspot is a disease caused by two seedborne fungi attacking cruciferous crops including cabbage, broccoli, Brussels sprouts, cauliflower, turnip rape and radish. All stages of the plant can be affected including the seed, which is a major source of infection. Infection at the seedling stage can lead to damping-off and stunting. In older plants, the older leaves closest to the ground are most affected. The fungi that cause the disease are widespread throughout the world (Figs. 1 and 2). The severity of the disease and losses vary widely due to weather conditions.

Fig. 1. Distribution of *A. brassicae*

Fig. 2. Distribution of *A. brassicicola*

The disease causes black spots surrounded by bright yellow rings on the leaves. These lesions grow and eventually destroy the entire leaf, resulting in loss of leaf area and premature ageing. The developing cabbage head may also be destroyed. Infection can increase in cabbages during storage. The disease can destroy a seed crop; seed yield losses of up to 70% have been reported.

Description

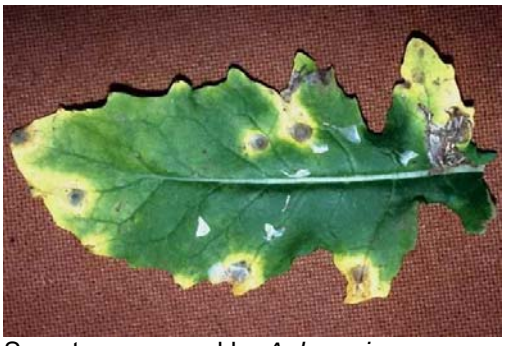
Alternaria leaf spot on cabbage

The fungus enters the plant through infected seed or from spores surviving in crop or weed debris. The fungi can be carried in and on the seed as conidia (asexual spores) or hyphae (fungal threads seeking for nutrients). Conidia carried on the seed coat can initiate infection of the plant. Infected seedlings have dark lesions on the stems, which can lead to damping-off, affecting crop yield and causing stunting. Conidia continue to be produced throughout the season, infecting the plant, causing lesions on leaves, stems, and flower heads. The first sign of infection is small dark spots on the leaves, which enlarge to become circular lesions surrounded by a bright yellow ring. These lesions continue to grow and can

cause defoliation if left untreated. Sometimes fungal spores will grow on these lesions. If the lesion dries out and falls out of the leaf, a shot hole effect is seen. Infection causes loss of leaf area and premature ageing.

Symptoms caused by *A. brassicae* are similar to those caused by *A. brassicicola*. However, the former causes grey to dark-brown to almost black lesions whereas *A. brassicicola* causes sooty-black lesions.

A. brassicicola leaf spots on cabbage



Symptoms caused by *A. brassicae*

The lesions can also infect the seed forming on the plant. Seed infections of up to 90% have been reported. The majority of infected seeds will develop into infected seedlings. Seeds can be lost during harvest, and seed quality and germination are poor.

Ecology

Fungal spores are carried on seeds and survive on weeds or crop debris. The spores are spread by wind and splashing water to initiate new infections.

Temperature and moisture are important to the development of the disease; optimal conditions are >91% relative humidity and temperatures of 18-24°C. Weather has a significant effect on the severity of the disease. Cool, wet weather or frequent rains and heavy dew favour disease epidemics.

Pest Management

As the fungi are carried on seed, the use of disease-free seed and seed treatments can control the disease. Hot-water treatment of seed is effective but can also affect germination. Fungicide seed treatments or the use of resistant or tolerant varieties could be explored.

Although it is difficult to avoid infection through crop debris, rotating the crop with non-cruciferous crops and removing cruciferous weeds can help to control the disease. Adjustment of sowing and harvesting times based on local weather conditions will also help to reduce the disease. Working in the field when the crop is wet could increase the disease spread.

Leaf spots on older leafs are usually problematic for yield. The economical impact of treatments should be evaluated in case the seedling stage is severely infested or when the cabbage heads got leaf spots.

Suggested exercises

Exercise	Page	Name	Time required
7.5	233	Study of symptom development of leaf spots: classroom exercise	½ day + ≤ 1 wk mon.
7.6	235	Study of symptom development of leaf spots: field exercise	½ day + ≤ 1 wk mon.
7.7	237	Effect of infection of the seed bed	1 day + 4–8 wks mon.
7.8	239	Effect of the use of infected planting material	1 day + 4–8 wks mon.
7.9	241	Test effect of hot water seed treatment	1 day + 4–8 wks mon.
7.10	243	Use of subsoil to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.11	245	Soil solarisation to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.12	247	Steam sterilisation to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.13	249	Test effect of infected crop debris in the field	Season-long weekly mon.
7.14	251	Effect of rain on the spread of leaf spot	Season-long weekly mon.
7.16	255	Test different cultivars for resistance to leaf spots	Season-long weekly mon.
7.17	257	Restricted fungicide use to manage leaf spots	Season-long weekly mon.
7.18	259	Study of spread of a fungal leaf spot	1 day + 4–8 wks mon.

mon. = monitoring

3.2 Soft rot - *Erwinia* spp.

Importance

Soft rot is a disease caused by a number of soil-borne bacteria, mainly *Erwinia* species. The disease affects many cruciferous and other crops causing a watery, soft, foul-smelling rot. *E. carotovora* subsp. *carotovora* is the main causal organism but other *Erwinia* species may be involved. *E. carotovora* subsp. *carotovora* occurs in all climates (Fig. 1), while *E. carotovora* subsp. *atroseptica* is found in temperate countries and in highland areas in the tropics. *E. chrysanthemi* may be involved at temperatures above 25°C.

Fig. 1. Distribution of *Erwinia carotovora* subsp. *carotovora*

Soft rot can occur wherever susceptible crops are grown. All stages of the plant can be affected but injured or damaged plants are most susceptible to infection. It is mainly a problem before harvest, because the disease can develop rapidly during transport and storage resulting in reduction or destruction of the marketable produce. Losses caused by soft rot can be great, depending on the value of the crop and the severity of attack.

Description

Cabbage soft rot

In temperate zones, the bacteria survive the winter in insects, the soil, on infected host plants and crop debris, and on cultivation equipment and tools. The bacteria enter the plant through natural openings or wounds caused by insects, disease organisms or mechanical means. Initial infection usually occurs on outer leaves close to the soil or on the main root or through wound sites caused by insects. Once inside the plant, the bacteria multiply rapidly and by using enzymes begin to digest the cell walls causing softening of the tissue.

The first sign of infection is small, water-soaked lesions on aerial parts of the plant or on plant parts in close contact with the soil. These lesions enlarge, and become soft and mushy. Infected leafstalks become water soaked and the bacteria spread to the head causing head rot. When infection occurs through the root, the pathogen spreads through the stem to the head. Under favourable conditions, the disease can reduce the tissues to a pulpy mass with secondary organisms causing further decay.

Cabbage soft rot

Cabbages and other cruciferous plants give off a foul odour when infected by soft rot.

Soft rot is particularly damaging in storage. Greyish-black lesions may appear on the leaves and stem. The disease progresses rapidly and can result in a wet, green, slimy mass within a couple of days.


Cabbage soft rot

Ecology

Soft rot bacteria can survive for long periods in the soil in cool, wet conditions. *Erwinia* species can cause disease over a wide temperature range but are inactive at temperatures above 50°C and below 4°C. Soft rot is favoured by temperatures above 22°C combined with high humidity. Temperature can determine the species of *Erwinia* involved in the disease and the rate of disease development. Soil moisture and temperature determine disease incidence and the symptoms produced. Soft rot bacteria need moisture for infection to occur and the disease is most common when fields are saturated with water. Overhead irrigation may promote the disease.

The disease can be spread by flies, by cultivation equipment, tools, clothing, and by irrigation water. Soft rot bacteria can be dispersed over long distances in very fine droplets that develop after rain splash or overhead irrigation on diseased plants.

Management

Soft rot is difficult to control and management of the disease relies mainly on sanitary and cultural methods. Good crop hygiene should be maintained in both the seedbed and the field. Plant debris and weeds should be removed from the field and from storage areas. Cultivation equipment should be thoroughly cleaned before use. Rotation of the crop with non-susceptible crops such as cereals or maize should be explored. Resistant crop varieties should be evaluated if available.

Care should be taken not to damage plants during cultivation, harvest, and storage. Planting should only take place in well-drained areas with adequate ventilation. Overhead irrigation should be avoided and crops should be dried after harvest before placing into storage. Any infected plants in storage should be removed and destroyed. Storage areas should be dry, well ventilated and maintained at low humidity without fluctuations in temperature to avoid condensation. Temperatures of around 4°C will inhibit infection. The use of buffering materials such as straw or paper can prevent injury to the crop in storage.

Copper sprays may offer some protection but these compounds only slow down the development of the disease and do not control it.

Suggested exercises

Exercise	Page	Name	Time required
7.31	285	Spread of cabbage soft rot by farming tools	1 day + 4–8 wks mon.
7.32	287	Effect of rain on the spread of cabbage soft rot	1 day + Season-long weekly mon.
7.33	289	Sanitation measures to manage cabbage soft rot	Season-long weekly mon.

mon. = monitoring

3.3 Downy mildew - *Peronospora parasitica*

Importance

Downy mildew is a disease caused by a fungus attacking the leaves and flowers of all cruciferous crops. The disease causes chlorotic spots on the leaves with a downy fungal growth on the underside. All growth stages may be affected but the seedling stage is most susceptible.

Fig. 1. World distribution of downy mildew

Downy mildew is widespread (Fig. 1) in temperate countries and occurs during the cool season in tropical regions. It is almost always present in cabbage fields. Infected seedlings can be killed and, if infection is not controlled in the seedbed, the disease can cause serious problems in the field. The disease is seedborne and, under favourable conditions, the fungus has been reported to infect up to 50-60% of cabbage seeds, subsequently reducing yield by 16-20%.

Description

Downy mildew symptoms on cabbage seedlings

Downy mildew symptoms on Indian mustard leaves

The fungus survives as resting spores in crop debris, cruciferous weeds, and on seed. These spores are spread during cool, damp weather and under suitable conditions can germinate and infect the plant. Fungal mycelium develops on the underside of leaves, producing large numbers of spores, which spread by wind or water.

In the seedbed, infection of the cotyledons and first leaves causes the leaves to fall off and may cause death of the seedling. The first sign of infection is the appearance of small, irregular, yellow-brown spots on the lower leaves, which expand and develop into greyish-black net-like markings on the leaves. A greyish-white, downy growth (mould) may be seen on the underside of the leaf spots in moist weather. Infected areas grow, become chlorotic and the whole leaf dies. After infected leaves fall off, the black rot bacterium (*Xanthomonas campestris* pv. *campestris*) is able to enter the plant.

The outer leaves of infected cabbage heads develop small, sunken black spots and may become unmarketable. Systemic infection can cause internal darkening of the cabbage head. The heads may also become susceptible to secondary rot pathogens in storage.


Downy mildew symptoms on chinese cabbage

Ecology

The disease occurs mainly in crowded seedbeds and along the shady edges of fields. It is spread by wind and water during cool, wet weather. High relative humidity (>98%) and leaf moisture encourage the production of spores and the spread of the disease. Cool, damp weather (heavy fog, light rain, prolonged dew), night temperatures of 10-16°C and day temperatures below 24°C provide ideal conditions for the spread of this disease. It is most severe after several days of favourable conditions, particularly when plants remain wet until mid-morning.


Downy mildew symptoms on the underside of chinese cabbage leaves. This is where sporulation can be observed in the field

Management

Sanitation and crop rotation could be explored for managing downy mildew. The disease is most difficult to control during periods of high humidity and cool temperature. Overhead irrigation should be avoided and humidity in the plant bed reduced. Clean, well-drained soils will reduce the potential for disease. Rotation with non-cruciferous crops for a minimum of three years can help to control the disease.

Crop debris should be removed after harvest and composted to remove this source of infection. Cruciferous weeds should be also removed and destroyed/composted.

Spraying with protective fungicide (low volume sprays or dustings) should only be used as a last resort.

Suggested exercises

Exercise	Page	Name	Time required
7.5	233	Study of symptom development of leaf spots: classroom exercise	½ day + ≤ 1 wk mon.
7.6	235	Study of symptom development of leaf spots: field exercise	½ day + ≤ 1 wk mon.
7.7	237	Effect of infection of the seed bed	1 day + 4–8 wks mon.
7.8	239	Effect of the use of infected planting material	1 day + 4–8 wks mon.
7.9	241	Test effect of hot water seed treatment	1 day + 4–8 wks mon.
7.12	247	Steam sterilisation to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.13	249	Test effect of infected crop debris in the field	Season-long weekly mon.
7.14	251	Effect of rain on the spread of leaf spot	Season-long weekly mon.
7.16	255	Test different cultivars for resistance to leaf spots	Season-long weekly mon.
7.17	257	Restricted fungicide use to manage leaf spots	Season-long weekly mon.
7.18	259	Study of spread of a fungal leaf spot	1 day + 4–8 wks mon.

mon. = monitoring

3.4 Black leg - *Phoma lingam*

Importance

Black leg is a disease caused by a soilborne fungus infesting most cruciferous crops. The leaves are attacked causing pale-brown lesions with grey centres and small black specks. The disease then spreads to the stem causing black, water-soaked lesions (black leg) at the base of the plant. As the plants mature, the weakened stem causes poor growth and the plants wilt, fall over and die.

Fig. 1. World distribution of black leg

The disease is widespread in cool temperate regions of the world (Fig. 1). Black leg used to be the most destructive disease of crucifers but has become less important due to the use of effective control measures. However, it is still a disease of major economic importance. In Australia, severe epidemics have occurred in cauliflower, fodder Brassica and cabbage-growing areas with losses of up to 90%. The severity of the disease is related to the amount of rainfall in the early summer.

Description

Resting spores of the fungus (ascospores) are the main source of black leg infection. They can persist for about 3 years on seeds or in residues of infected crops grown in the previous years and in cruciferous weeds. The spores are released during warm and humid weather and dispersed by the wind. The spores land on a leaf surface and, under favourable conditions, infect the plant. Wounds can facilitate the fungus entering the plant. The first sign of infection is small, pale-brown lesions on the leaves with grey centres and many small, black specks, which contain spores of the fungus. These spores can spread the disease to neighbouring plants during wet weather. The fungus spreads down to the main stem causing black, water-soaked lesions (black leg). The stem lesions enlarge and extend to the roots. In the advanced stages of the disease, the root system develops a dry rot. When the roots die, the plants become stunted. Leaves wilt but tend to remain attached to the stem instead of defoliating like plants infected with black rot. Older infected plants may lean or fall over and the affected plant usually dies.

Seeds are an important source of infection in cruciferous vegetables. When infected seeds are planted, the fungus lives on the dead seed, fruits in the soil and is able to attack the emerging cotyledons of viable seed. Seedlings are often killed or have sunken, black cankers at the stem base, which causes stunting.

Ecology

Spores of the fungus can survive for up to three seasons in the soil or in crop residues. The spores are dispersed by the wind and can be transported for up to several kilometres. Contaminated equipment and footwear can also spread the

disease within and between fields. Warm, humid weather favours the dispersal of spores and the spread of the disease. Epidemics occur when there is wet weather just before or during crop establishment. Once the disease is established in the crop, it can be spread to other cruciferous crops by rain, rainsplash or wind.

Seeds are an important source of infection in cabbages as seed infection can multiply under the high humidity and high density planting conditions of the seedbed. Epidemics may result when contaminated transplants are taken to the production field.

Pest management

Crop hygiene is very important in the control of black leg. Rotating the crop with other non-cruciferous crops can reduce the source of infection and field sanitation minimises the release of spores from infected residues. Field selection and planting date are also important factors in avoiding infection. Chemical control of black leg can be effective, especially when directed at critical points in the disease cycle.

Where possible, disease-free seed and transplants should be used. A hot-water treatment of 50^{o}C for 25 to 30 minutes can be used to disinfect seed, but this treatment is not always effective and can affect seed quality. Fungicide treatments can eradicate the fungus from seed. The success of seed treatments has reduced the importance of the disease.

Suggested exercises

Exercise	Page	Name	Time required
7.19	261	Seed drenching/coating to manage damping-off	1 day + 4–8 wks mon.
7.20	263	Use of subsoil to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.21	265	Soil solarisation to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.22	267	Steam sterilisation of soil to manage damping-off in the nursery	1 day + 4–8 wks mon.

mon. = monitoring

3.5 Club root – *Plasmodiophora brassicae*

Importance

Club root is caused by a soil-borne fungus attacking all cruciferous crops and several wild plants. Leaves wilt, become yellow and die. Below ground, swellings (galls) develop on roots, which become distorted and clubbed. All the growing stages are susceptible, but seed is not infested.

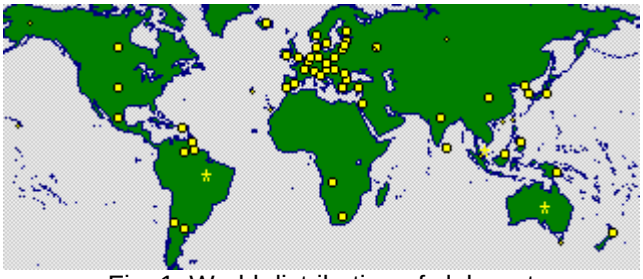


Fig. 1. World distribution of club root

Club root is widespread worldwide, especially in mild, moist temperate regions, but it is also prevalent in tropical and subtropical areas. In several countries, it has been estimated that club root infestation occurs on more than 10% of the land on which cruciferous crops are grown. It is considered one of the most economically important diseases of cultivated crucifers. In Australia, annual losses of crucifer crops caused by club root are estimated to be at least 10%.

Description

Wilted cabbage plant infected by club root

Initial foliar wilting is followed by reddening of the leaves

Resting spores in the soil germinate, possibly stimulated by chemicals produced by growing plant roots (exudates). The fungus enters the plant through wounds or root hairs and multiplies in the root tissues, causing the roots to become distorted. The clubs are full of fungal spores. The life cycle continues with release of spores into the soil after the roots have died and rotted. Spores may survive in the soil from 7 to 20 years .

A sign of infection is wilted leaves that become first red, then yellow and may eventually die. Young plants may die outright, and older ones fail to produce marketable heads.

The roots become stubby and develop swollen clubs or galls up to 15 cm diameter. The root tissue also develops soft rot, decays and smells bad. The distorted roots may be confused with the symptoms of insect damage.

Gall formation causes nutrients to become diverted towards the roots, affecting the development of the rest of the plant. The disease rarely kills plants, but causes them to wilt under slight water stress.


Club root of cabbage


Club root of cabbage

Ecology

The club root fungus is transmitted as resting spores in soil, by wind and water and can be transported on footwear, farm tools, machinery, infected plants, planting material (including non-crucifers) or animals. Different races of the fungus exist, which vary in their ability to cause infection.

The amount of yield loss depends on several factors, including the level of spores in the soil and time of infection. High soil moisture content and temperatures above 20°C are important for successful infection. An early attack on a field with high infestation could lead to complete crop failure, whereas a late attack with low infestation may pass undetected. Disease is more severe if soils are wet during and after transplanting or seeding. Epidemics develop quickly as the intensity of cultivation of cruciferous crops increases. The survival of the fungus in the soil restricts crop rotations: if susceptible hosts are planted, the amount of fungus will increase, causing further infections.

Pest Management

Young plants can be infected and not show any symptoms such as swelling of the roots. It is important that only seedlings grown in disease-free soil are used. The first real step in control is thus the location of seedbeds in an area where no diseased cabbage has been grown, where no contaminated plant material occurs, and where no infested soil can be washed. In infected areas, removal of infected roots is essential.

Raising soil pH above 7.0 using forms of lime is a traditional control method, but results may vary in different soils and climates. Lime should be applied at least 6 weeks before planting. Applying fertilizers with elements of calcium may lower occurrence of club root. The use of disinfectants during propagation is being investigated. Some soil sterilants may be effective. Attempts to identify suitable fungicides have met with little success.

The use of crop rotations that avoid cruciferous crops is a longer-term means of control, leading to a decline in the amount of resting spores in the soil over time. The fungus can survive in the soil for at least seven years after an infected crop so long

rotations should be used. Crop rotations also prevent the build up of lime in the soil. Soil solarization or the use of 'trap' or 'catch' crops have also been suggested. Cruciferous crops that resist infection also exist.

Suggested exercises

Exercise	Page	Name	Time required
7.4	231	Demonstration of spread of pathogens	½ day
7.25	273	Pot experiment to test whether root diseases are soil-borne	1 day + 4–8 wks mon.
7.26	275	Use of subsoil to manage clubroot in the nursery	1 day + 4–8 wks mon.
7.27	277	Steam sterilisation of soil for the nursery	1 day + 4–8 wks mon.
7.28	279	Soil solarisation to manage clubroot in the nursery	1 day + 4–8 wks mon.
7.29	281	Test effect of soil solarisation in the field	Season-long weekly mon.
7.30	283	Effect of liming on clubroot of cabbage	Season-long weekly mon.

3.6 Damping-off – *Pythium*, *Rhizoctonia*, *Fusarium* and *Phytophthora* spp.

Importance

Damping-off disease is caused by several different soil-borne fungi, including *Pythium* species. When a wet soil is heavily infested with *Pythium*, any seed, or young plants that emerge from seeds in such a soil, may be attacked by the fungus.

Damping-off is widespread worldwide, occurring in tropical and temperate climates, and in greenhouses. The disease affects seeds, seedlings, and young transplants of a wide variety of cultivated crops. The greatest damage is done to the seed and roots/shoots of seedlings during germination either before or after emergence. Disease losses vary considerably with soil moisture, temperature and other factors.

Description


Healthy and damping-off infected seedling

When the host plant is present, resting structures of the pathogen germinate and attack seedlings. Cabbage seeds rot or seedlings collapse, the main stem becomes rotten and shrivelled at soil level. Seedlings rot and collapse.

Seedlings in seedbeds, once infected often get destroyed by damping off, or die soon after being transplanted. Poor seed germination or seedling emergence is often the result of infections before emergence. Older plants are seldom killed by infection, but can develop root and stem lesions or root rots. Growth may be slow and yields are reduced. When infection is severe, the lower portion of the stem can become slimy and black and the roots rot so that the outer part can be easily separated from the inner core.


Damping-off infected cabbage seedlings

Soft fleshy organs of some vegetables, including cabbage heads, are sometimes infected during extended wet periods in the field, or in storage at the market. Such infections result in a cottony fungus growth on the surface of the fleshy plant part, while the interior becomes a soft, watery rotten mass, called 'leak'.

Damping-off during seedling emergence may be confused with plant injury caused by insect feeding, or the effects of excess fertilizer or fluctuations in temperature or moisture. Damping-off fungi rarely attack transplants in the field or established seedlings.

Ecology

The fungi occur naturally in the soil where they survive as resting structures. When a susceptible host plant is present and the climatic conditions are favourable, the population can develop rapidly to damaging levels. Transmission is mainly through

infested soil or growing media, and infected vegetative propagating materials and plant debris. Higher soil moisture and warmer temperatures favour disease development. Optimum growth occurs at 25-30°C.

Pest Management

Disease-free propagating material should be used to prevent transmission.
The fungi can survive in soil for over a year. No single crop should be planted in the same field for more than two consecutive years as this would increase the amount of fungus in the soil.

In greenhouses, heating or pasteurization may help eliminate the fungi. Soil solarization may be practised in the field or nursery.

Free water is important for disease development. Efforts to reduce soil moisture for example, improving soil drainage or planting on raised beds, will reduce disease severity. Clean sand can been used as an inert medium in the nursery to improve seedling emergence.

Mineral fertilizers (e.g. phosphorous, potassium, silicon, gypsum, dolomite, calcium) or soil amendments (e.g. composted bark, manure) may reduce disease. Avoid application of excessive amounts of nitrate forms of nitrogen fertilizers. Biocontrol agents such as *Trichoderma* and *Gliocladium* could further improve the disease reduction ability of compost.

The use of chemically treated seed can be effective against seed rot and damping off. Fumigation of soil could be done in the nursery, but is not recommended for environmental reasons.

Suggested exercises

Exercise	Page	Name	Time required
7.19	261	Seed drenching/coating to manage damping-off	½ day + 4–8 wks mon.
7.20	263	Use of subsoil to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.21	265	Soil solarisation to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.22	267	Steam sterilisation of soil to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.23	269	Raised plant beds to reduce damping-off	1 day + 4–8 wks mon.
7.24	271	Effects of inundation of fields on incidence of damping-off	1 day + 4–8 wks mon.

mon. = monitoring

3.7 Bottom rot - *Rhizoctonia solani*

Importance

Bottom rot is caused by a soilborne fungus that mainly attacks low-lying crops such as cabbage and lettuce. It is mainly a problem on cabbage and other head-forming crucifers. Bottom rot affects the leaves closest to the ground producing reddish-brown, slightly sunken lesions. Secondary rots cause the leaves to become dark brown and slimy. The infection spreads to other leaves and ultimately most of the leaves and the head will be invaded and rot. If lesions are too deep, plants will be discarded.

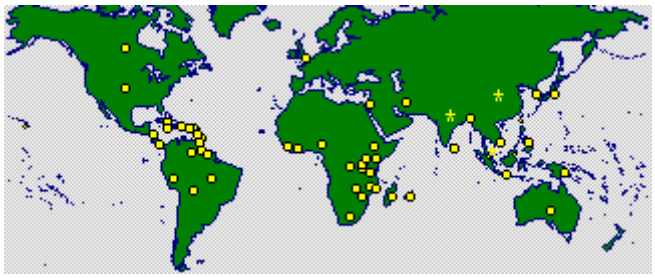


Fig. 1. World distribution of *Rhizoctonia solani*

The fungus causes a number of diseases on a wide range of plants worldwide. It has a very widespread distribution (Fig. 1) and probably occurs in all arable soils throughout the world.

Description

The fungus overwinters as resting structures (dormant mycelium or sclerotia) in soil, plant debris, seed or host plants. These resting structures germinate in the soil producing mycelium, which grows on the surface of leaves that touch the soil. Once the cabbage head begins to form, the lower leaves become infected by the mycelium resulting in dark brown, oval lesions on the leaves closest to the ground. Other decay organisms enter through the infection site and cause further decay making the lesions soft and watery. Infected cabbage leaves may wilt exposing the head. The infection spreads upward from the lower leaves to the next leaves and continues to spread until most of the leaves and the head are diseased. If only the outer leaves are affected, they can be removed in the field and harvested, but if the lesions are too deep, the plants will be discarded.

Ecology

The fungus can survive for long periods in the soil and is spread with the movement of infested plant parts and soil. It is also spread with rain, irrigation or flood water and by contaminated tools and equipment. The disease is severe in soils that are moist, but not in waterlogged or dry soils. Warm, moist conditions are favourable to the development of the disease. Vigorously growing, healthy plants are able to withstand infection, so environmental conditions that affect the growth of young plants will affect the severity of the disease. The amount of fungus remaining in the soil from previous crops will affect the incidence of the disease and so the crop history of the field is important.

Pest management

Control of bottom rot is limited to cultural methods although some fungicides are available. Careful irrigation, especially late in the season, and effective drainage are important and it is best to avoid planting in wet or poorly drained areas, especially during the early stages of seedling growth. Plants should be widely spaced for aeration of the soil surface and of plants. Seedbeds should be prepared before planting and, if possible, seeds should be planted in conditions that will let the seeds germinate faster and grow more vigorously. Transplants should not be planted too deeply in soils that have previously been affected by the disease. Crop rotation and ploughing the soil to bury the sclerotia (long-lived compact mass of vegetatively produced hyphae or fungal threads) may also help to control the disease.

Suggested exercises

Exercise	Page	Name	Time required
7.19	261	Seed drenching/coating to manage damping-off	1 day + 4–8 wks mon.
7.20	263	Use of subsoil to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.21	265	Soil solarisation to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.22	267	Steam sterilisation of soil to manage damping-off in the nursery	1 day + 4–8 wks mon.
7.23	269	Raised plant beds to reduce damping-off incidence	1 day + 4–8 wks mon.
7.24	271	Effects of inundation of fields on incidence of damping-off	1 day + 4–8 wks mon.

mon. = monitoring

3.8 Black rot - *Xanthomonas campestris pv. campestris*

Importance

Black rot is a bacterial disease that affects all crucifers, but it is most damaging to cabbage and cauliflower. All stages of the crop can be affected. The disease causes large yellow to orange 'V'-shaped lesions on the margins of the outer leaves, browning of the affected area and blackening of the veins. Infected cabbage heads often do not reach full size and the lower leaves fall off.

Fig. 1. World distribution of black rot

Black rot is widely distributed (Fig. 1) and is considered the most important disease of crucifers worldwide. The disease can be very severe, resulting in total loss of the crop.

Description

Black rot symptoms in cabbage field

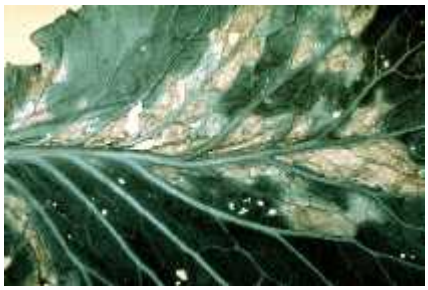
The disease is largely seedborne, but infected crop debris, plants and soil are also sources of infection. The bacteria enter the plant either through the seeds or through natural openings or wounds on the leaves. In young cabbage plants raised from infected seeds, cotyledons show discoloration in the margins, which later turn black, shrivel and drop off.

In older cabbage seedlings, the bacteria enter the lower leaves through natural openings. Large, yellow to dark brown lesions form in the shape of a wedge or 'V' along the margins of the lower leaves. These lesions may be surrounded by pale green, withered tissue.

V-shaped discoloration during initial stage of black rot in cabbage

Brown tissue develops in centre of discoloration

Progressing stage of black rot infection



Black rot lesions on cabbage leaf

Severely infected cabbage head with black rot

As the disease progresses, the lesions turn brown and the tissue dies. Stunting, discoloration, wilting and defoliation may be seen and some plants may be deformed. The veins turn dark brown to black with a narrow yellow halo. The pathogen enters the stem and spreads to other parts of the plant, e.g. leaves and roots. When cut open, the stems, and the stalks and midribs of infected leaves show internal brown discoloration. The heads are invaded and become discoloured. Symptoms may be more severe on one side of the head and infected heads often do not reach full size. Secondary soft rot may occur during periods of high temperature when the plant is near maturity destroying the head and giving off a foul-smelling odour.

Plants that show no signs of infection are common until flowering. Pods from infected plants may show shrivelling and discoloration and early invasion of pods usually results in the abortion of all seeds. Plants growing from infected seeds will have the disease.

Ecology

The bacterium overwinters in soil, crop residues, cruciferous weeds and seeds. It can survive in the soil for up to two years. The disease can be spread with surface water or irrigation and through contaminated tools and cultivation equipment. The disease develops slowly or not at all at low temperatures but spreads rapidly in warm, wet conditions. Spread does not generally occur in dry weather. Symptoms appear 7-14 days after infection at 25-30°C, which is the optimum temperature for the growth of the bacterium. Crowded growth conditions help to spread the disease to nearby plants and it can spread rapidly from a small number of infected seeds in a seedbed. Black rot can be seen to move along rows of the crop as it spreads, often as a result of cultural operations. It is most severe in low, shaded areas of the field that remain wet for a period of time.

Pest Management

Management of black rot focuses on controlling the pathogen in the seed and removing it from the soil. Where possible, disease-free seed or transplants should be used. A number of chemical, biological, antibiotic and physical seed treatments can be used to disinfest seed. A hot-water treatment of seeds at 50°C for 25-30 minutes is effective, but may affect germination and seed vigour.

Crop hygiene is very important. Infected plants and plant debris should be removed from the field, and composted or burned immediately after harvest. Cruciferous weeds should be removed from around the field. Rotation of the crop with non-cruciferous crops will help to control the disease, and soil drainage and air movement in the field should be improved. Control of other pests may help to reduce the disease as the bacteria can enter the plant through leaf injuries caused by insect pests. Chemical control is not widely applied, but copper fungicides may be effective in reducing the spread of the disease.

Suggested exercises

Exercise	Page	Name	Time required
7.5	233	Study of symptom development of leaf spots: classroom exercise	½ day + ≤ 1 wk mon.
7.6	235	Study of symptom development of leaf spots: field exercise	½ day + ≤ 1 wk mon.
7.7	237	Effect of infection of the seed bed	1 day + 4–8 wks mon.
7.8	239	Effect of the use of infected planting material	1 day + 4–8 wks mon.
7.9	241	Test effect of hot water seed treatment	1 day + 4–8 wks mon.
7.10	243	Use of subsoil to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.11	245	Soil solarisation to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.12	247	Steam sterilisation to manage leaf spot diseases in the nursery	1 day + 4–8 wks mon.
7.13	249	Test effect of infected crop debris in the field	Season-long weekly mon.
7.14	251	Effect of rain on the spread of leaf spot	Season-long weekly mon.
7.15	253	Spread of leaf spot disease by farming tools	1 day + 4–8 wks mon.
7.16	255	Test different cultivars for resistance to leaf spots	Season-long weekly mon.

mon. = monitoring

4. Beneficial Fact Sheets

4.1 Important Predator Groups

Background

Predatory and plant feeding species may have a very similar appearance. Often the only way to tell predators from pests is by observation of their feeding behaviour, or by making insect collections or 'insect zoos' to demonstrate with farmers which species may be beneficial or harmful in their fields. It is important to realize that not all predators prey at the same time. Many species are active during the night, while others search for prey during the day. This could lead to differences in observations and offers good material for discussions during or after the exercises.

Learning different insect collection and observation techniques can enhance farmers' observational skills and understanding of the agro-ecosystem.

Most people are familiar with at least some predators, and live specimens or pictures of predators can be useful in introducing the concept of biocontrol in training. An effective way to introduce a session on biological control is to make up interlocking 'jigsaw pairs' of pests with their respective natural enemies, e.g. a predatory bug with a caterpillar. You can include predators, parasitoids, some pathogen pictures, and maybe weed control agents. Each participant receives a card with a picture of either a pest or a natural enemy, and they have to find their corresponding 'partner', according to the interlocking pattern. You can include some explanatory text on the back of the cards.

Pictures often show magnified organisms, which could lead to wrong perceptions and confusion. Therefore, these visual aids by no means replace, but rather complement observations in the field.

The following section may serve as a guide to the major predatory groups of arthropods that are important in biocontrol in cabbage. Most of the illustrations of predators included here show the insect magnified many times. The small lines or blacked out images to the right of the pictures indicate the real (although approximate) size of the predator. The type of predator species may vary from country to country and hence pictures shown do not necessarily represent the species encountered in your field, but reflect the general kind of predators which could be encountered.

Table 2. List of major predators and their pests attacked.

Predators	Popular name	Cabbage pests attacked	Page
Coccinellidae	ladybird beetles	aphids, whiteflies, lepidopteran eggs	91
Carabidae	ground beetles	lepidopteran eggs and larvae, aphids and whiteflies	91
Staphylinidae	rove beetles	eggs and soft-bodied insects	92
Reduviidae	assassin bugs	aphids, small caterpillars and insect eggs	92
Anthocoridae	pirate bugs	aphids, thrips, mites and small caterpillars	92
Pentatomidae	shield bugs	thrips, caterpillars and insect eggs	93
Syrphidae	hoverflies	aphids, thrips, small caterpillars	93
Cecidomiidae	midges	aphids	93
Vespidae	wasps	wide range of caterpillars	94
Formicidae	ants	insect eggs, larvae, pupae and adults	94
Chrysopidae	lacewings	diamondback moth, thrips,	94
Dermaptera	earwigs	eggs, larvae and nymphs of smaller soft-bodied insects	95
Orthoptera	grasshoppers and crickets	lepidopteran eggs	95
Thysanoptera	thrips	whiteflies and other small insects	95
Araneae	spiders	diamondback moth, flea beetles, wide range of caterpillars	95
Acarineae	mites	thrips	

Predatory Beetles

Coccinellidae

7-15 mm

A coccinellid or **ladybird** larva attacking an aphid is pictured on the left. Both larvae and adults are predatory, feeding on aphids, lepidopteran eggs and other soft-bodied insects. Ladybird larvae are much less familiar to many people than the adults. They hatch from yellowish cigar shaped eggs laid on plants and feed on host prey before pupating on plant stems or leaf undersides.

Coccinella septempunctata larva

Many of the larger adult ladybird beetles are brightly coloured (pictured below), being red, orange, or yellow and frequently spotted or striped with black. Body length ranges from 0.8 to 16 mm. Adults may also feed on pollen and nectar of flowers to get extra energy.

8-16 mm

Micraspis crocea adult attacking aphid

Carabidae

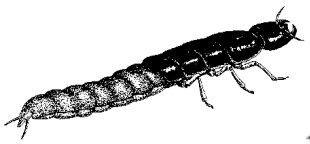
Carabids or **ground beetles** are predators moving fast over plants and soil surface, especially at night. Adult and larvae feed on a range of eggs, larvae, pupae (in or on the soil), and soft-bodied insects. Ground beetles are often shiny with grooved wing cases (pictured on the right). Larvae are usually elongated with well-developed legs and powerful mouthparts, and are active predators in the soil.

Nebria brevicollis *10-14 mm*

Staphylinidae

10-40 mm

Staphylinids or **rove beetles** (shown on the left feeding on a caterpillar) are a common group of predators and scavengers, feeding on eggs and soft-bodied insects. They are usually black or brown coloured, with short wingcases, exposing much of the abdomen, and when threatened they may flex the abdomen and release an unpleasant odour. They often drop from the plant when disturbed.



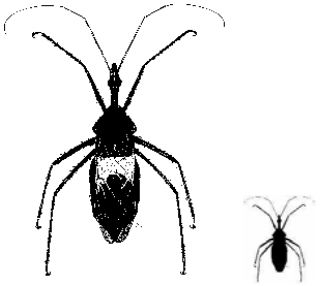
5-30 mm

Larvae (pictured on the left) usually live in the same habitat as the adults, feeding on similar prey. Many species live in soil, leaf-litter or decaying animal matter.

Predatory Bugs

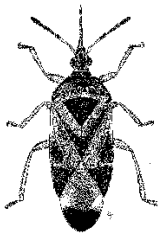
Reduviidae

Reduviid bugs are also also known as **Assassin bugs**. They are medium to large elongated bugs with distinct curved mouthparts held under the body. They move slowly, lying in wait for a variety of insect prey before injecting it with a paralysing toxin. Assassin bugs feed mainly on aphids, small caterpillars and insect eggs. They are solitary predators and rarely become numerous. The nymphs are smaller wingless versions of the adult and also predatory.



15-40 mm

Anthocoridae



3-5 mm

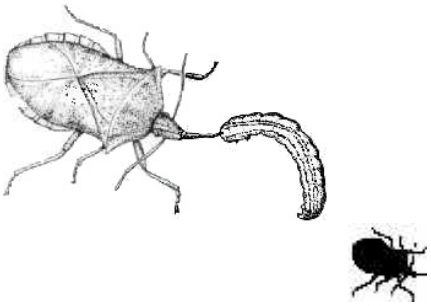
Orius sp.

2-3 mm

Anthocorids, or **pirate bugs**, are tiny predators (the adult and nymph are shown on the left top and bottom, respectively). Both life stages attack thrips, mites, small caterpillars and aphids. They are mostly found on flowers, but also under loose bark or decaying litter. Most are black with white markings and are 3-5 mm in length. They may also feed on pollen and plant juices. Unlike many predatory bugs, anthocorid populations may be large and reduce pest levels significantly. They are nearly all predaceous, usually of small insects and insect eggs. Orange-coloured nymphs often feed on insect eggs, sucking out the contents.

Pentatomidae

Pentatomid or **shield bugs** may be plant feeding or predatory. Predatory species like this one pictured on the right, and some of the stink bugs suck the juice from caterpillars, beetle larvae and insect eggs. Shield bug nymphs are rounder in shape than the adults, and are usually brightly coloured.



15-20 mm

Predatory Flies

Syrphidae

Episyrphus balteatus 6-10 mm

Syrphid fly

5-10 mm

Adult syrphids are called **hoverflies** (shown on the left) because of their remarkable ability to maintain stationary positions in flight. They are small, usually brightly coloured flies, often seen visiting flowers for nectar and pollen. Many species resemble bees or wasps. Females lay their eggs singly on plants near aphid colonies, which serve as prey for the hoverfly larvae.

Hoverfly larvae (pictured on the left, below) are slug-like maggots which can consume several hundred aphids during their development. Despite being leg-less, they actively move among foliage, particularly at night. They may also feed on small caterpillars and thrips in a typical fly fashion, by liquefying prey tissue and then sucking it up.

Cecidomyiidae

Many cecidomyiid flies are gall-forming midges on plants, but there are some species with predatory larvae which attack aphids or scale insects. These maggots are conspicuous, usually orange or red, and paralyse their prey before sucking dry the contents, leaving a darkened empty corpse. *Aphidoletes* species (shown on the right) are now available commercially for aphid control in greenhouses.

Aphidoletes aphidimyza *3-5 mm*

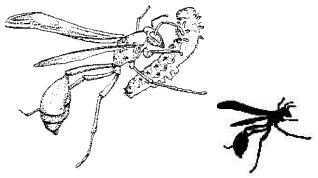
Predatory Wasps and Ants

Vespidae

True wasps are well known for their painful however are very beneficial, as they are efficient predators of a variety of harmful insects. Some are solitary, others live in colonies. Adults (pictured on the right, above) may feed on nectar, fruit or insects, but the larvae strictly feed on prey.

Paper wasp nest

In the tropics vespid **paper wasps** such as *Polistes* species (shown on the right, below) can play an important role in reducing pest levels. They often hunt for caterpillars and other soft-bodied prey in crops. Adult paper wasps are usually nectar feeders.



15-20 mm

Formicidae

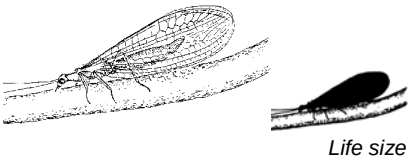
Ants are social insects, living in colonies. Many ant species are important predators attacking insect eggs (see picture on the right), larvae, pupae and adults. Adult ants search for and carry insect prey to the nest for the larvae and their own food. Besides feeding on insect prey, ants may also feed on nectar or on the sticky fluid (honeydew) secreted by plantsucking insects like aphids. Some ant species will drive away or kill natural enemies of these pests and are therefore considered as pests.

Solenopsis geminata 5-12 mm

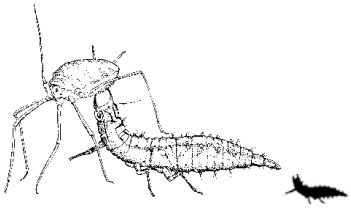
Other Predatory Groups

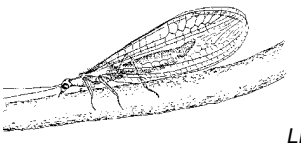
Chrysopidae

Chrysopid or **lacewing** adults (shown on the right, above) will fly long distances in search of food and they tend to be more active at night. Green lacewing adults feed only on nectar and aphid honeydew. Eggs are typically laid on stalks on the upper surface of leaves. **Chrysopid larvae** of lacewings (shown on the right below) are important and aggressive predators of aphids and mites but they may also feed on caterpillars and insect eggs. Several *Chrysoperla* species are commercially reared for mass release.



Life size





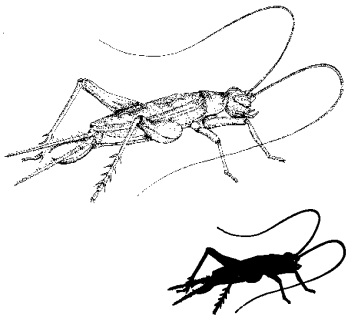
Life size

Dermaptera

25-30 mm

Most **earwigs** (Dermaptera) feed on decaying plant matter but some species are definitely predatory. They resemble rove beetles but can be distinguished by their forceps-like pincers used for defence. Many species are wingless and hide in the soil or in enclosed spaces during the day. At night they search plants for eggs, larvae and nymphs of smaller soft-bodied insects.

Orthoptera

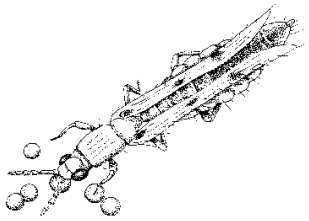


30-40 mm

Grasshoppers and **crickets** (Orthoptera) are usually herbivorous but some species may eat animal matter too. The long-horned grasshoppers, like the species pictured on the left, are known to eat lepidopteran eggs and planthopper nymphs as well as feeding on rice plants. Some crickets are also egg predators and may take small caterpillars and other prey.

Thysanoptera

Thrips (Thysanoptera) are usually pests of vegetables and flowers but some are predators. In certain ecosystems they can control spider mites. In cotton *Frankliniella* species larvae (pictured on the right) may destroy spider mite colonies by feeding on their eggs. Predatory thrips may also feed on whitefly and other small insects, while some species specialize on fungal spores.



2-3 mm

Araneae

Pardosa sp.

Spiders are not insects because they have 8 rather than 6 legs. All spiders, whether web spinners or hunting species, are active predators. They attack a wide range of insect prey, including pests and beneficial insects. **Wolf spiders** (shown on the left) are common in cabbage fields.

Suggested exercises

Exercise	Page	Name	Time required
6.1	117	Insect Zoo	½ day + ≤ 1 wk mon.
6.3	125	Sampling for arthropods with light trap	½ day + ≤ 1 wk mon.
6.4	127	Sampling for arthropods with sticky board	½ day + ≤ 1 wk mon.
6.5	129	Sampling for arthropods with water pan trap	½ day + ≤ 1 wk mon.
6.6	131	Studying predators in the field	½ day + ≤ 1 wk mon.
6.7	133	Soil-dwelling predators	½ day + ≤ 1 wk mon.
6.8	135	Direct observations of consumption rates of predators in the field	½ day or less
6.9	137	Micro habitat distribution of pests and natural enemies within the plant	½ day or less
6.15	149	Assessment of impact of ground-dwelling predators	1 day + 4–8 wks mon.
6.35	189	Predation on sucking insects in insect zoo	½ day + ≤ 1 wk mon.
6.36	191	Cage exclusion of natural enemies in the field	½ day + ≤ 1 wk mon.
6.43	205	Effect of pesticides on spiders and other natural enemies	½ - 1 day + 2-3 wks mon.
6.44	207	Role play on insecticide resistance	½ day or less

mon. = monitoring

4.2 Important Parasitoid Groups

Background

It is beyond the scope of this manual to include identification keys or full descriptions of all the families of parasitic wasps and flies. Even with a good key, and practice, most IPM practitioners still need to consult a specialist for accurate identification to species level. Identification is essential if you are introducing host-specific parasitoids as part of a classical biocontrol programme, but less important if you are trying to conserve natural enemies in the field. Larval stages of parasitoids are extremely difficult to identify to species level and specialists will usually need adult specimens. However, when working in the field, it may often be the larval or pupal stages that you encounter more easily.

This practical is set out as a brief, descriptive guide to the more important parasitoid groups that you may find in the field.

You may also want to use the practical as a training activity, using enlarged copies of the drawings mounted on card. One such activity is to prepare a wall-poster quiz with questions (related to the level of the participants), e.g. find two wasps that parasitize the egg stage of their host. Trainees select their answers from the drawings and/or text on display.

Pictures often show magnified organisms, which could lead to wrong perceptions and confusion. Therefore, these visual aids by no means replace, but rather complement observations in the field.

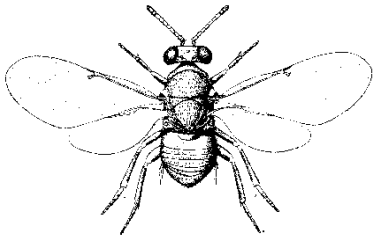
The pictures here are magnified; the small lines or blacked out images to the right of the pictures indicate the real (approximate) size of the parasitoid. The type of parasitoid species may vary from country to country and hence pictures shown do not necessarily represent the species encountered in your field, but reflect the general kind of parasitoids which could be encountered.

Table 3. List of major parasitoids and their pests attacked.

Parasitoids	Pests attacked	Page
Wasps (Hymenoptera)		
Encyrtidae	caterpillars, beetles, scales and mealybugs	98
Ichneumonidae	caterpillars	99
Braconidae	caterpillars and aphids	99
Trichogrammatidae	mainly lepidopteran eggs	100
Aphelinidae	aphids and whiteflies	100
Eulophidae	caterpillars	101
Pteromalidae	lepidopteran pupae	101
Chalcididae	lepidopteran and fly larvae and pupae	101
Scelionidae	eggs of several insect pests	102
Flies (Diptera)		
Tachinidae	caterpillars, sawflies, bugs and beetles	102
Bombyliidae	immature stages of moths, beetles or other flies	103

Parasitoid Wasps (Hymenoptera)

Encyrtidae

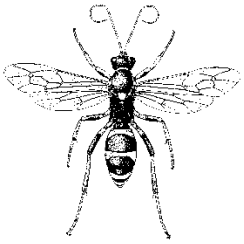


2-3 mm

Encyrtid wasps, like the *Blastothrix* species on the left, form one of the largest and most widespread parasitoid families. They are extremely important in biocontrol. Adults are tiny or small wasps, usually less than 2 mm, and like other families in the chalcidoid superfamily, their antennae are distinctly elbowed. Many are endoparasitoids of scale insects or mealybugs, but others attack a wide range of hosts including caterpillars and beetles. They parasitize insect eggs, larvae or pupae, but beware as some are hyper-parasitoids (parasitoids of a parasitoid).

Ichneumonidae

The family Ichneumonidae, which contains over 60,000 species, has many members that are parasitoids of cabbage insect pests, mainly Lepidoptera. They are endoparasitoids or ectoparasitoids of larvae and pupae. Most ichneumonids are relatively large and slender with long, curved antennae (16 segments or more). Females frequently have a long, distinct ovipositor.

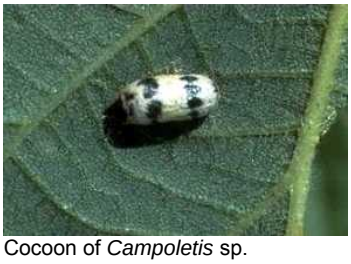


15-20 mm

Diadegma species insert a single egg, preferably in a second or third stage larva of for instance the diamondback moth. They are solitary endoparasitoids and the wasp larva develops together with the pest larva. Only after the pest larva has finished spinning a cocoon, the parasitoid larva starts eating it and forms their cocoon inside the host cocoon. The cocoon can be recognized because it is a double cocoon.

5-7 *mm*

adegma insulare



Cocoon of *Campoletis* sp.

Diadegma semiclausum

Braconidae

5-7 mi

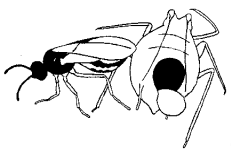
Cotesia plutellae parasitizing *Plutella xylostella*

Cotesia plutellae cocoon

Braconids, like the *Cotesia* species pictured on the left, are small to medium-sized wasps, and they are very common worldwide. They may be endoparasitoids or ectoparasitoids, and can be solitary or gregarious. Hosts include lepidopteran larvae and aphids. Many braconid larvae leave the dead host and spin a cocoon beside it. Gregarious species like *Cotesia* form a communal ball of fluffy silk over the cocoons.

Braconids belonging to the genus *Aphidius* parasitize aphids internally. They may pupate within the mummified body of their host, and emerge as adults from a neatly cut circular hole (as shown below). Others emerge as larvae from the mummy and then spin a tent-like cocoon under the host remains. Like ichneumonids, braconid antennae are long and curved, never elbowed.

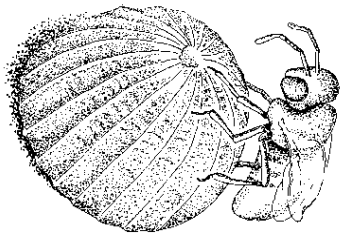
Aphidius sp.



3-4 mm (wasp)

Aphids parasitised by *Aphidius* sp.

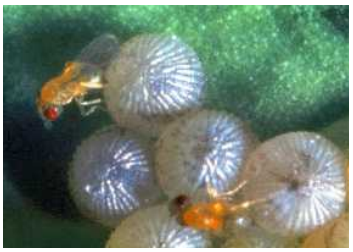
Trichogrammatidae



-
1-2 mm

Trichogrammatid wasps, like the one shown on the left, are stout-bodied, minute chalcidoids, which you can hardly see without a hand lens or microscope. They parasitize mainly lepidopteran eggs, with up to three wasp larvae developing in each egg. Most trichogrammatid species will attack a range of host species, and parasitized eggs turn black as the parasitoid develops inside. Adult wasps emerge from the darkened egg.

Mamestra brassicae eggs; those o the right have been parasitized by *Trichogramma*

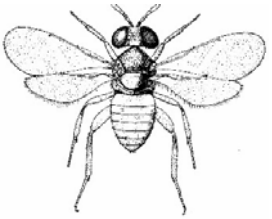


Pieris brassicae eggs parasitized by *Trichogramma*

Trichogramma brassicae

Aphelinidae

Eretmocerus sp., parasitic wasp on *Bemisia tabaci*



-
1.5 mm

Aphelinids are common chalcidoid parasitoids, usually under 1.5 mm long. They are one of the most important groups used in biocontrol introduction programmes against aphids, psyllids, mealybugs, scale insects and whiteflies. Members of the genus *Aphelinus,* pictured on the right, specialize as endoparasitoids of aphids, attacking any host stage. The parasitized host mummifies and darkens, before the adult wasp cuts a neat, circular emergence hole. Aphelinids attack a variety of homopteran hosts, but particularly non-mobile groups such as scale insects. *Aphytis* species attack armoured scales, laying their eggs underneath the host's shield.

Aphelinus asychis stinging aphid

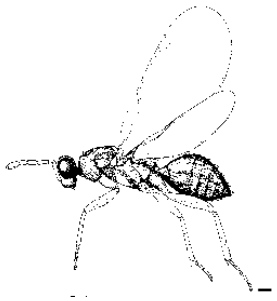
Encarsia formosana wasp hatching from whitefly scale

Whitefly scales parasitized by *Encarsia formosa*. (Bottom right, adult whitefly)

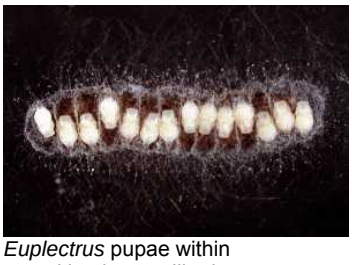
Eulophidae

Eulophids are a large group of small, often metallic-coloured, chalcidoid wasps. They are endoparasitoids or ectoparasitoids of eggs, larvae or pupae. The genera *Eulophus* (line drawing shown below) and *Euplectrus* contain gregarious species that parasitize exposed, leaf-feeding caterpillars. Females paralyse the host and attach their eggs to the outside of the body, where the larvae feed externally. Other eulophids attack eggs or leaf-mining larvae and many are hyperparasitoids.

Tetrastichus schoenobii

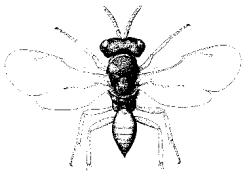


2-3 mm



Euplectrus pupae within parasitized caterpillar larva

Pteromalidae



3-5 mm

The Pteromalidae family is another very large group of small to medium-sized chalcidoid wasps, usually metallic in colour, with a coarse, pitted thorax. Their life histories are extremely varied, including parasitioids, hyperparasitoids, predators, and gall-formers. Some pupal parasitoids have been introduced for control of house and stable flies. *Pteromalus* species (line drawing on the left) are gregarious endoparasitoids of lepidopteran pupae.

Pachyneuron muscarum hyperparasitizing egg of *Diaphorencyrtus diaphorinae*, a parasite of the pest *Diaphorina citri*

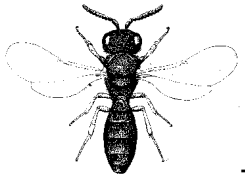
Chalcididae

Brachymeria sp.

Chalcidid wasps are fairly large (up to 9 mm long) and stout, with a sculptured thorax. The thigh (femur) on the hind leg is distinctively swollen and toothed. Most chalcidids are solitary endoparasitoids of Lepidoptera and fly larvae or pupae. *Brachymeria* species (shown on the left and right) attack a wide range of Lepidoptera, the species here attacks rice leaf-folders and skippers, the adult emerging from the host pupa.

5-7 mm

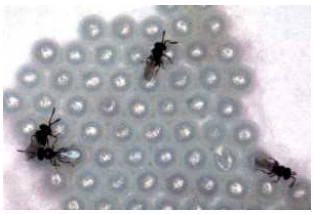
Scelionidae



3-5 mm

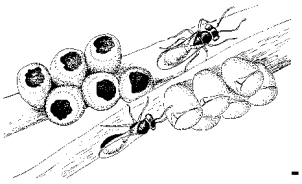
Scelionids are small to tiny egg parasitoids of a range of insect orders and also of spiders. Like pteromalids and chalcidids, their head and thorax may be sculptured and pitted. They also have elbowed antennae. Scelionids are one of the most successful families of egg parasitoids in biocontrol and have been released for control of moth and bug eggs. The scelionid species pictured on the left attacks grasshopper eggs.

Telenomus sp.



Telenomus remus on eggs of *Spodoptera littoralis*

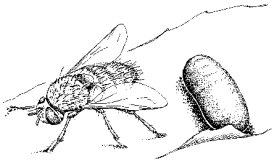
Trissolcus species of scelionid attack bug eggs. Parasitized eggs turn grey in colour and the adult wasp emerges through an irregular exit hole (as shown on the right) after 2-3 weeks. Although several scelionids may parasitize an egg mass, each host egg will only support one wasp larva. Females leave scent-markers as they oviposit to deter further attack. *Telenomus* species are used against eggs of lepidopteran pests.



1-2 mm (wasp)

Parasitoid Flies (Diptera)

Tachinidae

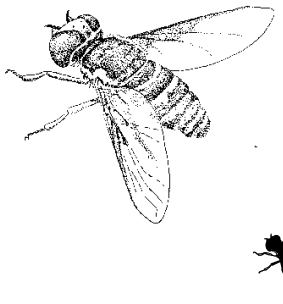


10-12 mm

Tachinid flies parasitize mainly caterpillars, sawflies, bugs and beetles. Adult tachinids are hairy and medium-sized, and similar to houseflies in appearance. Different species may lay eggs or newly hatched maggots on the host exterior or close by on the food plant. The host range of each species may be broad or narrow. This *Palexorista* species (pictured with its cocoon on the left) is specific to the African cotton bollworm, *Helicoverpa armigera*.

Exorista bombycis, a parasitoid of *Pieris brassicae*

Bombyliidae



10-15 mm

Bombyliid flies, like the *Exhyalanthrax* species shown on the left, are medium- to large-sized, and densely-haired or scaly. Their appearance gives rise to their common name of bee flies. The larvae of some species are parasitic on immature stages of moths, beetles or other flies. Some bombyliid flies hyperparasitize Hymenoptera. Other useful bombyliids attack the pupae of tsetse flies, and armyworm.

Suggested exercises

Exercise	Page	Name	Time required
6.10	139	Importance of flowers as food source to adult parasitoids (1)	½ day + ≤ 1 wk mon.
6.11	141	Importance of flowers as food source to adult parasitoids (2)	½ day + ≤ 1 wk mon.
6.16	151	Measuring the parasitism level of caterpillars	½ day + ≤ 1 wk mon.
6.17	153	Parasitisation on diamondback moth of cabbage	½ day + ≤ 1 wk mon.
6.18	155	Effect of parasitisation on feeding behaviour of diamondback moth	½ day + ≤ 1 wk mon.
6.28	175	Life cycle and biology of the parasitoid *Diadegma semiclausum*	½ - 1 day + 2-3 wks mon.
6.29	177	Life cycle and biology of the parasitoid *Cotesia plutellae*	½ - 1 day + 2-3 wks mon.
6.30	179	Life cycle and biology of the parasitoid *Diadromus collaris*	½ - 1 day + 2-3 wks mon.
6.31	181	Life cycle and biology of the parasitoid *Cotesia glomerata*	½ - 1 day + 2-3 wks mon.
6.32	183	Preference of host stages by *Diadegma semiclausum* (or *Cotesia plutellae*) (1)	½ - 1 day + 2-3 wks mon.
6.33	185	Preference of host stages by *Diadegma semiclausum* (or *Cotesia plutellae*) (2)	½ - 1 day + 2-3 wks mon.
6.34	187	Competition between *Diadegma semiclausum* and *Cotesia plutellae*	½ - 1 day + 2-3 wks mon.

mon. = monitoring

4.3 Entomopathogens

Pathogen Biology

Like any other plant, human or animal, insect pests are susceptible to infections caused by a wide range of pathogens, some of which show great potential as biological control agents. Pathogens enter the insect body by one of two routes:

- When the host swallows pathogen individuals during feeding (this is called passive entry).
- When the pathogen enters via natural body openings or direct penetration through the cuticle (this is called active entry).

Once inside the insect, the pathogen multiplies rapidly, eventually killing the host by the production of toxic substances or by depleting its nutrient supply.

Different Kinds of Pathogen

The most important groups of insect pathogens (or entomopathogens) are viruses, bacteria, fungi and nematodes, all of which are microscopic or submicroscopic (not visible with conventional light microscopes) in size.

Most pathogens are highly host specific and some, especially viruses, may infect only a single genus or species of host. This makes them attractive as biological control agents. Table 4 compares briefly the important characteristics of the various entomopathogenic groups.

Table 4. Characteristics of entomopathogenic groups.

Pathogen	Host range	Mode of entry	Speed of kill
Viruses 	Mainly Lepidoptera and Hymenoptera Often specific to one genus or a single species	By mouth	3-10 days
Bacteria 	Mainly Diptera and Lepidoptera Particular strains specific to different species	By mouth	30 minutes – 3 weeks
Fungi 	Very broad Many individual strains are host specific	Through the cuticle	4-7 days
Nematodes 	Very broad	Through the cuticle	6-10 days

Viruses

Viruses are submicroscopic bodies that consist of a core of genetic material with or without a protein 'overcoat'. They cannot reproduce or survive long-term outside the host tissues they infect. Several viruses are currently being exploited as agents against a wide range of lepidopteran pests such as diamondback moth, armyworms and bollworms. Unlike some other insect viruses, baculoviruses are considered to be environmentally safe, since they have not been proved to cause infection in vertebrates or plants, either in nature or experimentally.

Spodoptera larva infected by NPV hangs from top of plant

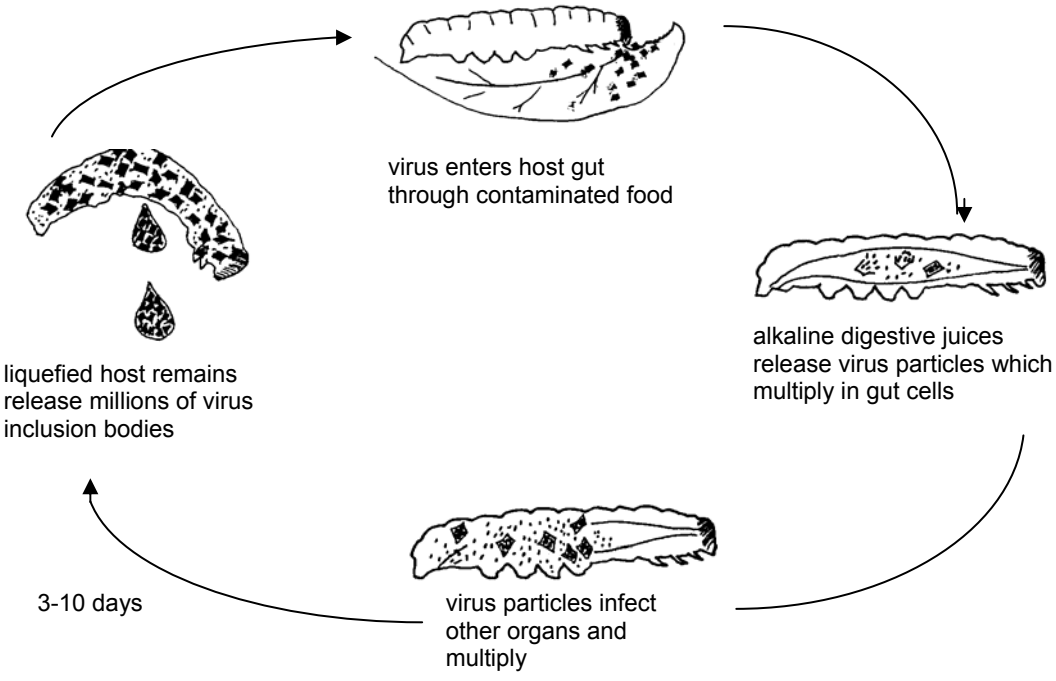
Viruses multiply by reproduction of their component parts (typically DNA wrapped in a protein sheath). These are then assembled to produce new virus particles within the host cell. Baculoviruses are often highly virulent and infection occurs after the susceptible insect larvae have eaten food contaminated with virus. The virus replicate in many tissues inside the insect and interferes with the movement, feeding and egg laying of the insect.

Figure 1 shows the stages in infection by a virus. The death larva will eventually become liquid and when the skin brakes, the infectious virus particles are released.

In granulosis and nuclear polyhedrosis viruses (NPV), the virus particles develop within a protein coat, called either 'granules' or 'polyhedra'. The protein coat preserves the infectivity of virus particles outside the host.

Naturally occurring viruses may infest caterpillars, which can be collected and used for local production of biopesticides. As with all on-farm made biopesticides, attention will have to be paid to quality control and safety. For secure results, commercial biopesticides should be purchased.

Figure 1. Life cycle of a typical entomopathogenic virus.



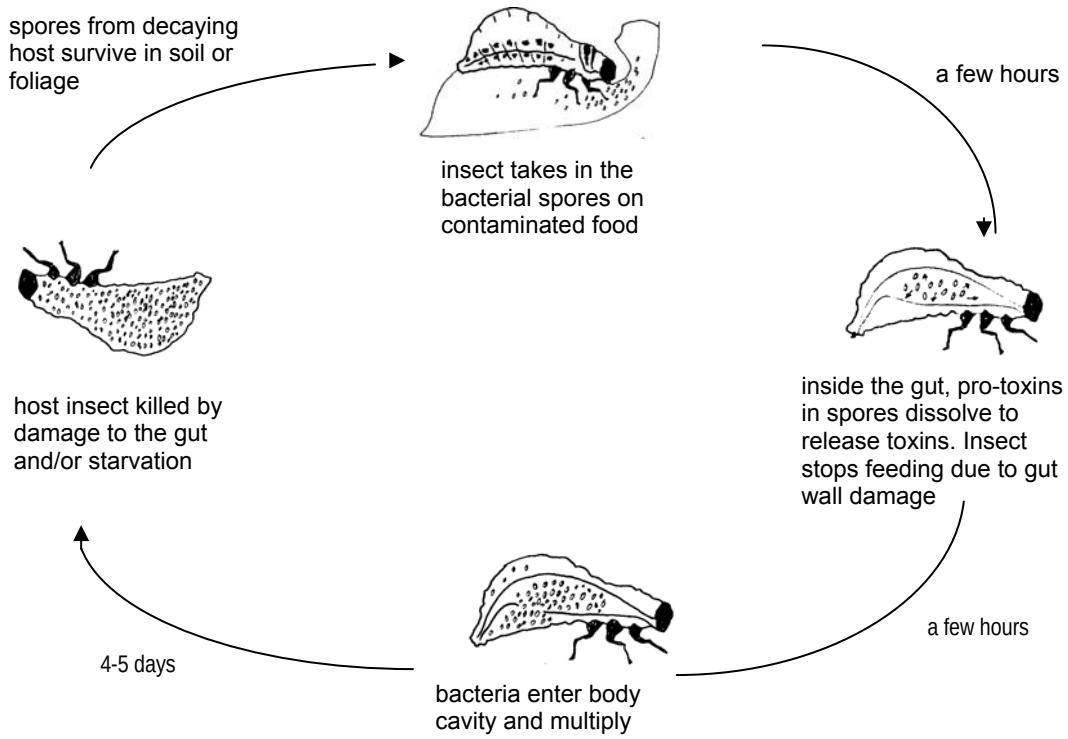
Bacteria

The principal bacterial control agents of insects are species of the genus *Bacillus*. Other potential pathogenic groups exist, but these micro-organisms typically only cause disease in weakened or stressed insects.

Bacillus bacteria are widespread in the environment and can be isolated easily from leaf surfaces and the soil. They are single celled, usually rod-shaped (bacilliform), and many species can be easily cultured. Infection occurs only after bacterial cells or spores have been eaten by the host and mainly affects herbivorous or aquatic larval stages. Figure 2 shows the life cycle of *Bacillus thuringiensis* (Bt). Depending on the variety of Bt, it may attack caterpilars, including this of the diamondback moth, beetles, mosquitos or black flies.

Dead larva at bottom is infected with *Bt* and becomes brownish-black and soft

Figure 2. Life cycle of *Bacillus thuringiensis*.



During spore formation Bt cells produce a toxin, but it is only once inside the susceptible host that this toxin becomes effective. The spores of the bacterium can enter the insect body cavity, where the bacterium multiplies. Although the host insect takes 4 or 5 days to actually die, it stops feeding within a few hours. So although it may appear to be slow acting, in fact the insect stops causing damage very soon after infection, which, at the end of the day, is what pest management is all about.

Fifteen Bt varieties have been distinguished so far, varying in host association and biochemical properties. Bt is available as a commercial microbial insecticide, and is often locally produced. They are generally effective and safe for natural enemies and can be sprayed with conventional equipment until close to harvest time. Caterpillars are best targeted in a young stage, and Bt should be applied in sufficient quantities for the caterpillars to die, otherwise only their growth is retarded.

Fungi

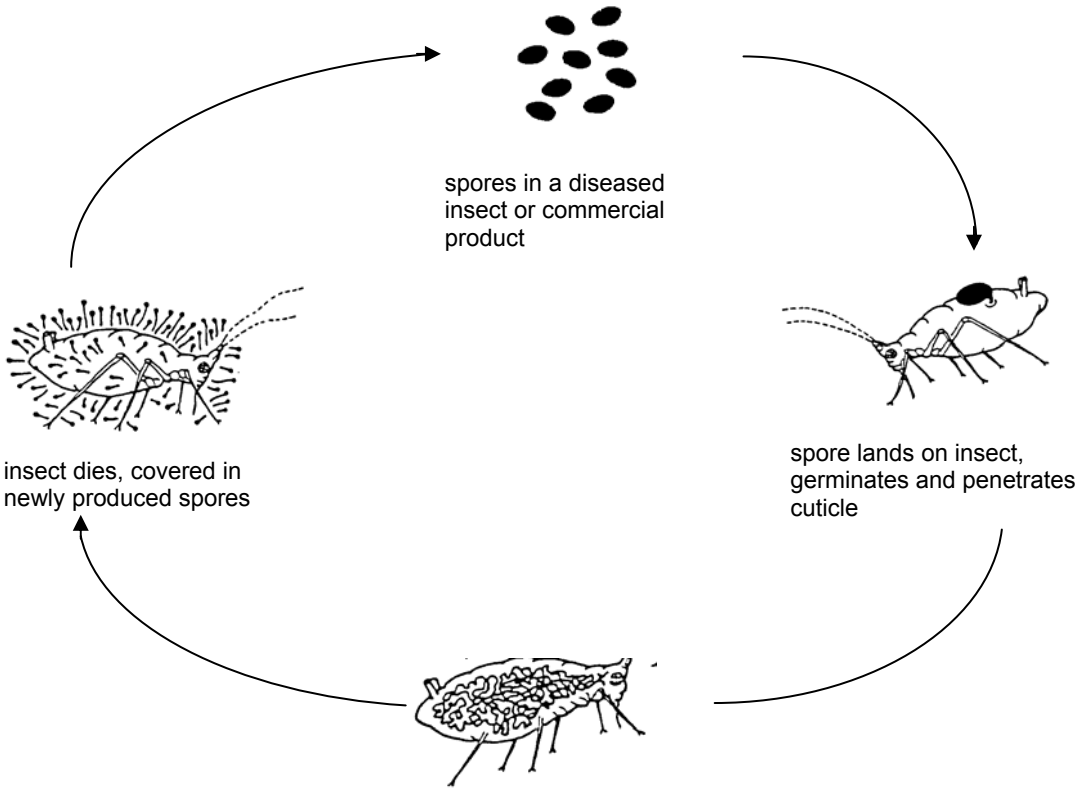
Fungi differ from other microorganisms, because they have cell walls containing chitin. The cells are organized to form characteristic filaments or strands (hyphae) which together make up a tangled mat known as the mycelium. Reproduction is mostly through forming spores, and these may be formed asexually or sexually.

Fungi that cause diseases in insects are called entomopathogenic fungi. These are not harmful to animals or plants. In the environment there are several species naturally present that can kill insects when conditions like humidity and temperature are favorable. Herbicides and other pesticides can inhibit or kill these beneficial fungi.

Larva on cabbage covered with white mycelium of an entomopathogenic fungus

Figure 3 shows a typical life cycle for these groups of entomopathogenic fungi. Almost without exception, they penetrate and infect the insect host directly through the cuticle, using a complex array of enzymes which are released as the spore germinates. Once inside the host body cavity, the fungus multiplies rapidly, and the yeast-like cells which are produced disperse throughout the insect body.

Figure 3. Life cycle of a typical entomopathogenic fungus.



In some fungal pathogens, the host usually dies only after the mycelium has grown extensively through the body, causing death by suffocation or starvation. In other groups, the insect dies as a result of toxins released early on in the infection process. The mycelium then develops feeding on the decaying corpse. As the hyphae grow rapidly and take up host nutrients and water, the dead insect dries up.

In the majority of entomopathogenic fungi, the hyphae break through the host cuticle only after death, typically when the insect has attached itself to a plant or concealed itself, depending on the host-pathogen combination involved. The external mycelium produces spore-forming structures and spores are liberated passively or actively to continue the infection cycle.

Collectively, fungi have a very broad host range amongst insects, and arthropods in general, but individual isolates of a species vary greatly in specificity. Many isolates will only infect a narrow range of closely related species. Some fungi can control sucking insects such as aphids and whiteflies which are not susceptible to bacteria and viruses.

Larva left are infected with *Metarhizium* fungi

Fungi like *Beauveria* and *Metarhizium* spp. are available as a commercial formulation. They are generally effective and safe for natural enemies and can be sprayed with conventional equipment or used in fungus-contaminated insect baits. You can also consider making your own biopesticides from dead insects. To be effective, care has to be taken that these fungi actually killed the insects and were not merely a secondary infection on the dead insects, which is part of the decomposing process.

Nematodes

Nematodes are small worms, thread-like organisms with a tough outer cuticle. For rhabditid nematodes, the largest free-living infective stage so far recorded is just over 1 mm. There are thousands of nematode species and many of them live on or in the soil. Many nematodes attack plants, and are a serious problem in many crops, others are parasites of animals and humans. There are also a large number of nematode species that are parasites of insects, the entomopathogenic nematodes.

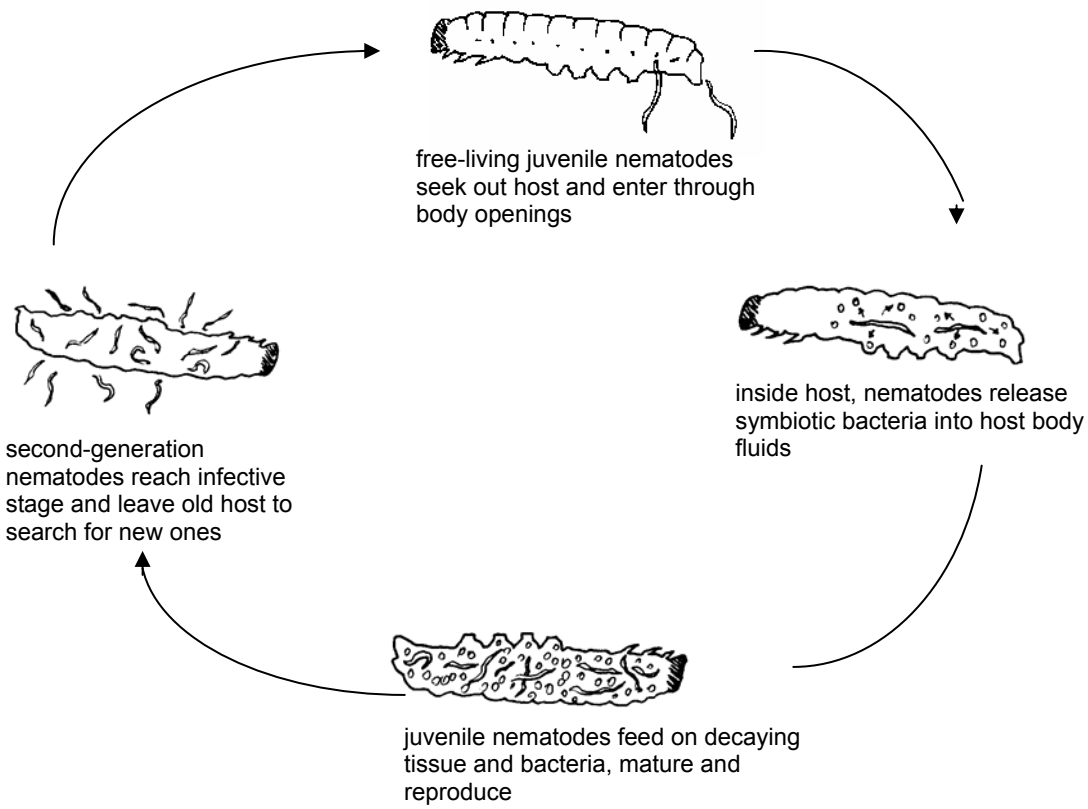
Although nematodes are extremely diverse, their life cycles tend to follow a basic pattern. They have life cycles like insects. They usually mate and following the egg stage, there are four larval stages, and one or more of these stages lives outside the host and is often referred to as a 'free-living stage'. It is during one of these free-living stages that the larvae seek out and infect their hosts, and this is referred to as the infective stage. For many species the infective stages can only move around in free water, i.e. they 'swim' through the soil water, searching for a host. The nematode passes through a number of stages of development within the host.

On a commercial scale, several entomopathogenic species belonging the genera *Steinernema* and *Heterorhabditis* are important. For these nematodes it is the third stage larva that is free-living and penetrates susceptible hosts, usually through the mouth or anus, and enters the body cavity through the gut wall. Once inside, the nematodes release very specialized bacteria which multiply in the body cavity, and it is the bacteria, or rather the toxins that the bacteria produce, that kill the insect in approximately 48 hours. The nematodes themselves do not cause the death of the host unless present in very high numbers.

You can often spot nematodes through the cuticle of the intact insect. After nematode infection, the host body changes colour as it dies due to bacterial action, and becomes yellow or brown (*Steinernema*) or reddish (*Heterorhabditis*).

The juvenile nematodes then feed on the decomposing contents of the body of the insect until the food supply is exhausted. Once this is the case they emerge as free-living, infective-stage larvae which disperse and find new hosts. Figure 4 shows the life cycle of a typical *Heterorhabditis* species.

Figure 4. **Life cycle of a typical entomopathogenic nematode.**



Suggested exercises

Exercise	Page	Name	Time required
6.45	211	How to collect and recognise insect pathogen groups	½ day or less
6.46	215	How to isolate and culture viruses and bacteria	½ - 1 day + 2-3 wks mon.
6.47	217	How to test the infectivity of nematodes to target insects	½ day + ≤ 1 wk mon.

mon. = monitoring