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Pest Reference

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Helicoverpa Reference

Taxonomic Identification

Scientific Name: *Helicoverpa* (*Heliothis*) *armigera* (Huebner)
Common Names: Old world bollworm (gram pod borer, tomato fruitworm)
Order: Lepidoptera
Family: Noctuidae

Distribution

The 'Old World' meaning Africa, Asia, Australasia and the Pacific Islands and Mediterranean. Mainly tropical and sub-tropical, but ability to enter diapause has allowed this species to extend into temperate zones, such as the South Island of New Zealand and southern Europe.

Related species of economic importance

- *Helicoverpa punctigera** (Wallengren)- Australia
- *Heliothis peltigera* (Denis and Schiffermueller) West Asia/North Africa southern Europe
- *Heliothis viriplaca* (Hufnagel) (= *dipsacae* (L.)) West Asia/North Africa southern Europe
- *Helicovpera zea** (Boddie) (= corn earworm, (New World) cotton bollworm and tomato fruitworm) - Americas
- *Heliothis virescens** (Fabricius) (tobacco budworm) - Americas

*These species, together with *H. armigera*, are the major pest species.

Helicoverpa or Heliothis?

Until the late 1980s the genus was uniformally known as '*Heliothis*', both as a scientific and common name. Whilst this name is still widely used it has been split by taxonomists into *Helicoverpa* and *Heliothis*. Here, we shall refer to *Helicoverpa armigera* as Helicoverpa. The following description is prepared with this species in mind, but much of it is common to the other pest species. If you need additional information about them please refer to your facilitator, and

http://www.ipm.ucdavis.edu/PMG/r114300511.html

Helicoverpa Reference

Description of Life Stages

Eggs

White when laid, darkening to grey-brown before it hatches. Infertile eggs become yellow and pointed. 0.5 mm, subspherical with a slightly flattened base. Magnification shows about 24 longitudinal ribs or ridges, with alternate ridges shorter, and much finer cross connections between the ridges.

Bollworm egg and small larva

Freshly laid bollworm egg on cotton square

Black eggs have been parasitised by Trichogramma.

Larvae

There are usually six larval instars, although this can range from five to seven. The maximum length is 35- 42 mm. If you need to distinguish between instars with certainty, you need to equip yourself with a microscope with a micrometer eye-piece to measure head-widths and a fine scale ruler or micrometer to measure their lengths (link to expansion of this technique)

Neonates (1º) translucent yellow-white when they hatch, with faint lines along the body; head capsule darkens to brown. A hand lens will show that the (schlerotized) thoracic and anal shields, thoracic legs, and spiracles are also darkened. Prolegs are absent on abdominal segments 3-6 and 10.

Second instar (IIº): darker ground colour, but lightening in colour of schlerotized plates.

Third to sixth instars (III-VIº): several colour forms cause confusion. The variation in colour increases from the third instar, which have a green or brown ground colour, through to the sixth. VIº can be blue-green, bright green, yellow green, yellow, pink, or light brown to reddish brown. The colour is in fact arranged in a series of lateral stripes - dark along the back, then pale then dark with a white-yellow stripe along the lateral-line where the black spiracles are situated. The underside is white or cream. The head capsule is blotchy, with light and dark brown mottling. The stripes are in fact further decorated with irregular patterns of stripes and patches.

Different colour variations of Helicoverpa

There has been much speculation about the reason for the colour variation (which occurs in the four major species) - genetic factors, the species and quality of the host, the temperature (and other environmental factors), and differential predation may all be implicated to varying degrees.

Pupae

14-22 mm long and 4.5 - 6.5 mm wide across the thorax and, as in most noctuids, they are a dark shiny brown.

Adults

The moths are stout bodied with a wingspan of 35-40 mm and a body length of 18-19 mm. The general colour of the body is also variable: greenish yellow, through cream to buff, grey and reddish brown. The top of the wings are a little darker, with brown markings - a band running close to the trailing edge, that is sometime broken into irregular blobs and crescents. Females are usually darker and larger than males.

Helicoverpa Reference

Duration of life stages

The length of the various stages depends primarily on temperature, but foo and quantity are secondary determinants for the larval stages. Humidity pr has less effect because the microclimate in which this species lives (i.e. in c proximity to a plant) features an atmosphere that is always saturated or clo

Stage	*Time*
Egg	2-5 days, 3 days in tropical Asia.
Larva	20-22 days on food of adequate quality assuming temperatur fluctuating at about 25ºC. As short as 13 days at 28-30º C.
Prepupa	1-4 days
Pupa	10-14 days in central India. 30 days at 15ºC and 6 days at 3
Diapausing pupae take several months to complete their developme	
Moth	Up to 18 days for females and 14 days for males.

The implication is that from first egg to first egg takes about 30-35 days. If adequate food is available and there is no diapause during a particular year can be 11 generations in a year.

Helicoverpa Reference

Biology of life stages

Larvae

When the larvae hatch they eat their egg shells and then wander around looking for a suitable place to eat - preferably a flower bud, flower or small boll. If they hatch before the plant is in the reproductive stage, they eat the leaves rather than starve. At first the larvae will eat the surface of whatever structure they find, but by the late second or third instar, they become borers and penetrate the fruit or buds to varying degrees - up to complete emersion. (What are the implications regarding the use of synthetic and microbial pesticides?). Their presence is usually given away to crop scouts and perhaps to predators and parasites by the accumulation of faeces outside the feeding hole.

When densities are high and when a large proportion of the food is consumed larvae become 'edgy' or hyperactive. They move around more and take 'bites' out of many bolls or buds. This is when they are most damaging because a large number of bolls have a small amount of damage and are lost because of contamination by spoiling fungi.

Prepupae and Pupae

When the larva has completed its development it falls or crawls to the soil surface and buries itself in the soil. The depth of the pupation depends on the soil type and the water content. It can be anything from 2 to 17.5 cm below the soil surface. The larvae shorten over a period of 1-4 days - these are the prepupa, and the exoskeleton then harden to form the pupal case.

If environmental conditions become too extreme (basically too hot or too cold) during the larval stage the pupae enter a diapause.

Pupal diapause

If Helicoverpa larvae are exposed to short photoperiods of 11.5-12.5h and temperatures in the range of 19-23ºC, the pupae will enter diapause - or at least some of them will. Populations close to the equator are less prone to diapause - but it can be induced in the laboratory. It is more likely to happen in populations living to the north and south, in the subtropics and temperate zones. Aestivation is induced in some populations by exposure to temperatures of 35ºC or more. It is ended by a consistent fall in temperature, such as that associated with the onset of monsoonal rains.

Helicoverpa Reference

Biology of life stages - Adults

Eclosion

Eclosion (emergence of moth from the pupa) takes place after dusk and before midnight, peaking between 2000 and 2300h. The newly emerged moths climb up suitable vertical objects and remain immobile for 2-3 h while the wings dry and expand. (Does this have any implications for an IPM component?)

Pheromone Release

Females start to release their pheromone (calling), indicating that they are physiologically prepared to mate, 2-5 days after eclosion. They call between 2200 and 0200, during which period males are actively seeking a plume of pheromone to follow.

Females release the sex attractant pheromone kairomone to attract male moths. This is a common modality found throughout the insects and other animals. The actual chemical is a blend of (Z)-11-hexadecenal (the major component), (Z)-9-hexadecenal and (Z)-11-hexadecenal-1-ol. Despite extensive research and development, internationally, the synthetic pheromone has not led to applications other than the monitoring of flight patterns. This is in marked contrast to applications in other species.

Mating

Mating lasts for 1-2 h. Females do not call after mating is complete until the following night. Temperature and humidity may influence mating: it is most likely to occur when temperatures fall and humidity increases.

Oviposition and fecundity

Egg laying - oviposition - is stimulated by mating. However, females are capable laying before mating but the eggs are infertile. Eggs are laid singly.

Opinion about whether female moths need to feed to produce eggs is somewhat divided. What seems true is that they do feed, whether they need to or not - for instance on aphid honeydew, the sticky secretion produced from ergot fungus on sorghum, pigeonpea sap flows and the extra-floral nectaries of cotton plants.

The actual number of eggs laid depends on the food quality and quantity of the larvae and adults, mating success, climatic conditions, access to suitable oviposition sites etc. As a matter of practical reality - nobody has been able to measure how many eggs are laid by the members of a field population. All we know is that, in laboratory conditions, they can lay 700 eggs, up to about 2000.

Helicoverpa Reference

Biology of life stages - Adults

Flight

Moths usually fly at night. After dusk they tend to search for nectar and other sources of energy. Related genera, such as Spodoptera, have to undertake a certain amount of flight activity before they lay eggs (they are obligate migrants). Helicoverpa is a facultative migrant. It only makes extensive flights if food conditions are unfavourable, if larval density is excessive, and if weather conditions are suitable.

It is possible to identify three types of flight activity:

- Local: where moths move around their 'home' crop and its immediate vicinity looking for food, oviposition sites (females) or mates (male). They do not fly much above crop height.
- Long-range flights of 1-10 km about 10 m above the crop height - and down wind. These result in the colonization of new crops.
- Migratory flights: These are believed to be stimulated when the larvae have poor food conditions.

Case history: In early 1991, Scientists in Hyderabad, southern India, collected moths that had high levels of pyrethroid resistance. This followed a period of cyclonic activity in the Bay Bengal that resulted in strong winds blowing from the East coast. As, at that time, pyrethroids had only been applied to (cotton) crops growing 4-500 km to the east (in Guntur District) this was taken as evidence that

Helicoverpa moths are able to fly (or at least be carried by air currents) for hundreds of miles. Cotton crops in Guntur had been decimated, thereby diminishing the availability of quality larval food.

Evidence from the study of DNA finger printing - in the context of monitoring insecticide resistance patterns - shows that, in Australia, most flights are 'local'. Note: this is in the Australian context, where fields are measured in 100s of hectares.

Oviposition in cotton

Eggs are mostly laid singly in the upper part of the canopy of cotton plants (leaves and buds). However, variety, the stage in the season and the behaviour of localized populations can influence the distribution of eggs.

How do moths choose of oviposition sites in cotton? For moths that do not migrate, the dominant behaviour pattern is to lay eggs on or close to the plant that they ate as a larva. Migratory moths are subject to a series of chemical and physical stimuli that draw the moth to the plant from many, perhaps hundreds of meters, or kilometers, away and guide them to the site of egg placement.

A possible sequence is the long distance location of a crop by detection of reflected light waves characteristic of a plant species - note that oviposition is lowest when the moon is full. This is construed to mean that the moonlight interferes with the reflection of long wave (super infrared waves) coming from the night sky. This has never been proved or disproved, but it does explain how moths locate isolated fields of a favoured host.

related research on H. zea in USA

Chemical vapours emitted by the crop attract moths up wind. Once in the crop the actual site on the leaf is selected by the sense of touch. The tip of the female moth's abdomen has sensors that enable it to differentiate between shiny or smooth leaves and hairy leaves (the preferred site). This is a simplification of a complex series of events that are not yet fully understood.

Perhaps you can think of better explanations of what happens between the time that a moth is half flying and half drifting on air currents I km up in the night sky and the time that she lays.

Important term used in descriptions of long migratory flights:

Boundary layer - altitude at which the airspeed (wind speed) equals the flight speed of the insect. The implication is that, if the insects' wings continue to provide uplift, the flight direction is greatly influenced by the direction of the wind.

Helicoverpa Reference

Population Dynamics

The importance of IV°, V°, and VI° Helicoverpa larvae

The critical fact with which pest managers have to come to terms, is that it is the IV°, V°, and VI° Helicoverpa larvae that reduce the yields of cotton plants, because they do most of the eating. They grow from a larva a little over 1 cm long weighing a couple of milligrams to a 4 cm, 2 g 'monster'. In the 12 days this phenomenal growth has taken place they will have eaten 20 times their weight of plant material - 80 g - and will have damaged 2 or 5 or even 10 bolls.

Thus we have to bear in mind that in economic terms the success of a control method hinges on the number of larvae that are prevented from moulting from III° to IV°.

There is in fact an additional practical twist to that comment. Once a larva has entered IV°, it is difficult to kill with an intervention, because

- it feeds (by boring) inside a plant organ so that stomach insecticides are ineffective,
- it does not walk around the plant over much so that contact insecticides are ineffective, and
- the larger it gets, the more pesticide is required to interfere with the metabolism of a larva.

The corollary is that non-pesticidal methods of control are needed to supplement pesticidal methods aimed at the eggs and smaller instars.

Helicoverpa Reference

Population Dynamics

There are two over-riding influences on the number of larvae that moult to IV°.

1. The migration of fertile females into the field from close and far (and the number of eggs they lay).
2. The amount of mortality of eggs and I°-III°.

Immigration

Pest managers can do little to stop moths migrating and arriving in fields, but they can monitor the process with pheromone traps and by the surveillance of crops for eggs. It is a common experience for there to be periods of intense oviposition over a series of perhaps 10 nights. This is a characteristic of Helicoverpa. If natural enemy populations are not sufficiently high, a repeated insecticidal intervention is called for. The critical fact here is that eggs can hatch in as little as 3 days so that an ovicidal intervention would be need to be applied at three day intervals during periods of high oviposition.

Egg and larval mortality.

The potential for an 'explosion' of larvae is high. There is a high rate of recruitment of adults and this species has a high fecundity. Thus a lot of eggs are laid very quickly. It would be disastrous if the all survived. Research on the population dynamics of Helicoverpa shows that most of the eggs and neonates die due to 'natural causes'. This comment is made because it has not been possible to enumerate the various factors involved. Researchers have naturally taken the line that if they know how the mortality occurs they would be able to take steps to enhance the various mortality factors.

Convergent lady beetle feeding on bollworm egg

We can divide the mortality factors into two kinds (excluding the apparent mortality that results from the likelihood that a small proportion of the eggs are infertile).

1. Those that are associated with the abiotic features of the environment, such as the weather conditions. Rain (or overhead irrigation) can drown the larvae or wash off eggs; wind can result in eggs being brushed of a leaf. In the case of Helicoverpa these factors undoubtedly can and do occur. They also operate independently of the density of the eggs or larvae. For this reason they are called density independent factors. These are particularly important in Helicoverpa because they regularly account for the most of the early stage mortality.
2. Those that are associated with the biotic features of the environment, specifically other animal species and pathogens. We can list these as
   - Natural enemies - predators, parasites and entomopathogens (insect disease organisms).
   - Neutrals - those species that appear to have no direct bearing on the survival of Helicovperpa. These should not be ignored. They may become pests if their natural control processes are damaged by pesticides aimed at other species, or they may be an alternative food source for the natural enemies of a pest species.
   - Included in this class of organisms are members of the same species. Helicoverpa is cannibalistic. Neonate larvae eat their own egg shells

when the hatch, and have been observed to eat the egg shells of their siblings - before they hatch.

Here it is necessary to point out that predators and parasites search for their hosts or food and will naturally aggregate where they find most prey. This results in more individuals being parasitized or eaten. There is thus a relationship between the density of the host or prey and the number or proportion of that die. They are therefore described as density dependant mortality factors.

In many textbooks on ecology these have been the sole focus of considerable interest. In our present context we need to consider another group of factors - those concerned with the host plant. This is because the plant has the ability to defend itself from insects and mites that want to eat it.

There is a huge body of knowledge of this subject, so we shall restrict our attention to some of the factors that could influence Helicoverpa and other insects living on cotton. Here are some of the factors that can influence the survival of the Helicoverpa egg or the larva that hatches from it.

Helicoverpa Reference

Management Options

It is not surprising to find that Helicoverpa, as a pest of cotton and many other important crops, has attracted the attention of crop managers and researchers with a wide range of interests - virtually every specialization you can think of. It can be stated, with non-judgemental frankness, that we know much about the ecology of this insect and the factors and approaches that might be taken to manage Helicoverpa, but it still remains the worlds #1 pest. Some of the research has lead to clear conclusions about why a particular approach will or will not lead to a satisfactory IPM component. Others, whilst brilliant in concept, may have led to concepts that are not practical within the orbit of contemporary farming practices.

Integrated pest management (per se) in cotton has to accommodate a number of pests or potential pests and will be addressed elsewhere. Here address some of the components as they relate to Helicoverpa alone.

Host Plant Resistance

The agricultural research programmes of countries where cotton is important have, in their germplasm collections cotton genotypes with resistance to Helicoverpa and other pests. Scientists have made large investments into seeking resistance to Helicoverpa but conventional breeding programs have not repaid this investment in he form of plants growing in farmers' fields.

Resistance characteristics include:

- Antibiosis - genotypes with high levels of gossypol and other terpenoids.
- 'Okra' leaves, glaucous (shiny) leaves combined with the absence of nectaries (nectariless)
- Avoidance - compact habit (short duration)/ determinant growth habit.

Helicoverpa Reference

Management Options

Putting it all together - Integrated Helicoverpa management

In many parts of Asia, Helicoverpa is the main cotton pest so that is sensible to think in terms of this single pest. This is largely because the neonicotinoid seed treatments have reduced the damage caused by the sucking pests of the vegetative stage. A disadvantage of this success is that the predators of the sucking pests have not been attracted to the crop and are not there when Helicoverpa migratory flights first begin.

Farmers in southern India have been advised to provide for this by sowing rows of cowpea, soybean or mung bean in their crops, with barriers of maize or sorghum, even sunflower. These crops are usually colonized by aphids and other sucking pests (that will not attack the cotton) and serve as foci for the build of predators such as ladybirds and lacewings. They provide additional food security or a cash source. They do not interfere with cotton production because they are harvested after about 80 days, by which time they have done their job.

The installation of bird perches - as many as 20 per ha early in the crop cycle so that the birds can learn that they are there. This contribute to reducing the number of large larvae that escape the other management procedures.

A strategy for rationalizing insecticide application for Helicoverpa management is:

1. Delay the application of pesticides as long as possible, especially when predators are easy to find.
2. When the first eggs are anticipated (from pheromone trap catches), apply a repellent such as a neem preparation in an attempt to divert the moths
3. If this fails be prepared to apply an ovicide such as methomyl or profenofos. This may have to be repeated after 2-4 days (how long is the egg stage?) during times of intense adult activity. But the same material should not be applied more than three times in succession during a cropping season if resistance is to be avoided.
4. If larvae are known have escaped the ovicides (i.e. if second or third instar larvae are found) and option is to apply a NPV or Bt preparation, remembering that it takes 5-7 days for the larvae to die. They continue to eat during most of this period, so 'the earlier the better'. If this is not feasible a growth inhibitor is an alternative, as is a commercial pyrethroid-organophosphate cocktail. If insecticide resistance is not proven or

suspected, there are many other options open. Local knowledge will be a key to success.

Firstly and lastly farmers should be entreated to get rid of the crop trash in sufficient time to allow two three generations of clean fields before the next sowing and to plough the fields deeply to kill diapausing or residual pupae.

Spiny Bollworms (Earias spp.) Reference

Taxonomic Identification

Scientific Name: *Earias* spp. (Huebner)
Common Names: see distribution table below
Order: Lepidoptera
Family: Noctuidae

Distribution of Economically Important Species

Common Name	Species	Distribution
Spiny bollworm, Egyptian boll worm	*E. biplaga* Wlk.	Widespread, important in India
Spiny bollworm	*E. insulana* Boisd	Widespread
Spotted bollworm	*E. vittella* F.	Widespread
Rough bollworm	*E. buegeli* Rogenh.	Australia
	E. cupreoviridis Wlk.	China, Africa, SE Asia

Spiny Bollworms (Earias spp.) Reference

Description of Life Stages

This is a general description because the immature stage are superficially similar.

Eggs

The eggs are <0.5 mm in diameter, bluish with 30 longitudinal ridges. Alternate ridges project upwards to form a crown.

Larvae

The larvae grow to about 18 mm long. Each segment has a number of long hairs. Each segment has two pairs of tubercles ('lumps') - two on the back and one on each side. The ones just behind the head are largest. The base colour is light brown, with various patches of grey or green, depending on the species. The length and distribution of the hairs and tubercles varies form one species to another. There are five instars - sometimes four.

Pupae

The pupae are light to chocolate brown and about 13 mm long. They are usually found in a cocoon attached to the host plant, more rarely in or on the soil.

Adults

The moths are 12 mm long with a 21 mm wing span. The abdomen and hind wings are silver or cream. The thorax and wings vary according to the species:

Forewings

- *E. insulana* - the ground colour varies from silver-green to light yellow.
- *E. vitella* - the ground colour is creamy white to peach with a central green wedge running from the leading edge to the trailing edge of the wing.
- *E. cupreoviridis* - forewing is metallic green ,with a golden patch, one or two distinctive dark spots in the centre of the wing and a broad chocolate margin (NB the specific name means 'copper green').

Spiny Bollworms (Earias spp.) Reference

Duration of Life Stages

Eggs hatch in three days. The larval and pupal stages both last about two weeks, and there is a three day preovipositon period. Thus the life cycle, egg to egg, is completed in close to five weeks. The adults can live for up to two months in captivity.

Biology of Life Stages

The eggs are laid singly, around the top of the plant, and on the buds and fruit as they develop. *Earias* is more of a stem borer than the other 'pod' borers. The entry point of choice is the terminal bud. The larvae only burrow in the soft tissue. It can be imagined that any stem thus attacked becomes non-functional. The stems stops growing, the leaves droop, and the whole stem dies. Growth restarts at lower lateral buds.

When they attack the reproductive parts - buds, flowers and bolls they dig into the green organs and move around between structures. This means that they cause more damage than might be supposed from an assessment of their density.

There is no pupal diapause.

Moths rest in the day and fly at night. They mate in the early morning from the second day after emergence. They lay about 200 eggs.

The favoured hosts are all malvaceous plants - with a handful of records recording that maize and sorghum can also be colonized.

Spiny Bollworms (Earias spp.) Reference

Management Options

In trying to understand why these species can be pests we need to look for clues at the life cycle in particular.

In the case of Earias:

There is no diapause: This means that if there are alternative hosts available during the non-crop season it can continue to multiply and reinvade after sowing. If there are no hosts and the climate is unfavourable the populations will be depleted.

The adult lives for a long time: this means that they can stay in a given domain in the fallow period and lay eggs, for instance, after a significant rainfall event stimulates the growth of its alternative host plants.

From this it can be imagined that - as with PBW - field hygiene is important. Thorough ploughing to destroy trash and pupae will clear the immediate area of a source of reinfestation for the previous season.

An effective male attractant pheromone exists so that flight monitoring can be encouraged in Earias-prone areas (see box).

Economic status

Unlike Helicoverpa, for instance, which has a predilection for plants' reproductive structures (and a wide choice of hosts), Earias damages all stages of the plant. It can appear especially serious in the first 20-30 days because the young plant has only one to several terminals - which are killed. Throughout its range these species are sporadic in terms of their appearance in one place and not another, and on one season but not the next - even within a season.

Host plant resistance

- High levels of resistance are available in several non-cultivated species of Gossypium.
- G. hirsutum is more susceptible than G. barbadense.
  Resistance has been associated with high levels of gossypol, the nectariless character and okra leaves. However, reports to the contrary also exist.

Thus researchers have a lot of work to do on this species.

Insecticides

This species is susceptible to organophosphates and pyrethroids. Its reduced status is believed to be a result of the application of these materials in 'general' non-specific spray programs.

Resistance is always a risk. Organochlorine resistance was recorded in the 50s. after three years exposure.

Natural Enemies

Many parasites of this genus have been recorded, but very few predators are known. The egg parasites are mymarids and trichogrammatids. There are about 30 larval parasites known in Africa and about the same number in India. The most potent natural enemies are entomopoathogens, such as Serratia, Bacillus cereus and a cytoplasmic polyhedrosis virus.

The high level of parasitism and disease in this species imply that natural control process could play a greated part in the management of this pest. For instance the release of Trichgramma might provide an effective management tool. Also, its susceptibility to entomopathogens is also open to exploitaion. However, his pest rarely acts alone so any associated activities would need to be integrated with the IPM program for a crop as a whole.

Cultural Control

Cultural control focuses on the destruction of pupae by the incorporation or destruction of crop trash and by heavy ploughing.

Putting it all together - Earias IPM

This species tends to build up from one generation to the next. Thus careful monitoring of this species and its natural enemies is needed. The decision about if and when to apply a pesticide us will be guided by locally determined thresholds - relating crop stage and potential loss to the costs of interventions.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Taxonomic Identification

Order: Lepidoptera
Family: Gelechiidae

- *Pectinophora gossypiella* Saunders - Pink Bollworm (PBW)
- *Pectinophora scutigera* Holdaway - Pink-spotted bollworm (PSBW)

Other Gelechiidae that are also pests in Asia

- *Maruca vitrata* - gram pod borer
- *Aproaerema modicella* groundnut leaf miner

Distribution

Pink bollworm

PBW is found throughout the tropics and sub-tropics and has been found in all cotton growing areas except Queensland Australia, Russia and Uzbekistan, Central America and Ecuador, Guyana and Surinam. It can be the dominant yield constraint, but fluctuates considerably between seasons and locations.

It was first recorded to be a cotton pest in India in 1842. It spread into Sri Lanka, Burma (Myanmar), Malaysia. By about 1910, it had reached China and Australia. Its spread through Africa was less rapid. It was first recorded in Tanzania in 1904 and Egypt in about 1906, but no record existed in Malawi until 1939 and in Zimbabwe until as late as 1959.

The New World infestation started in Hawaii in the early 1900s as a result of contaminated seed from India. It moved into the Caribbean from Hawaii. Mainland infestation started in Mexico through seed imported from Egypt - thence to Texas in 1917 and the rest of the USA, despite stringent attempts to isolate infested areas. It finally arrived in California in 1965 and Nevada in 1966.

Pink-spotted bollworm

PBSW is restricted to Eastern and Northern Australia (Queensland and the Northern Territory and possibly northern New South Wales), Hawaii, Micronesia, and Papua New Guinea. This species is found in southern Queensland and occasionally in New South Wales. It is of minor status because it is sensitivity to organophosphate and pyrethroid insecticides applied for the control of other insects. Its appearances in farmers' fields can be traced to improper destruction of crop trash at the end of the previous season. It is essentially similar to PBW.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Centre of Origin

The origin of these species is not clear. It is interesting to study the techniques that scientists use to study this subject. It is equally interesting to learn that, despite the methods that they use, they still cannot come to a consensus.

Scientists like to work out where a given species originally came from. This because this is where they are most likely to be a concentration of the predators and parasites of a given species. If a biological control program is planned this is where the collections would be made.

Also this information would provide information about the climatic zone to which a pest is most likely to be adapted. This would tell us which parts of the world are potentially at risk to infestation, so that quarantine or other legal instruments covering the movement of unprocessed cotton and cotton seed could be imposed.

A species that is not a pest in its centre of origin can be presumed to me 'under the control of' its natural enemies. If it is a pest it may be because the cultivation of the crop has changed. In the example in hand, PBW is believed to have become a pest in India in the 1850s because American upland cotton was introduced to replace the 'native cottons', *Gossypium arboreum* and *G. herbaceum*.

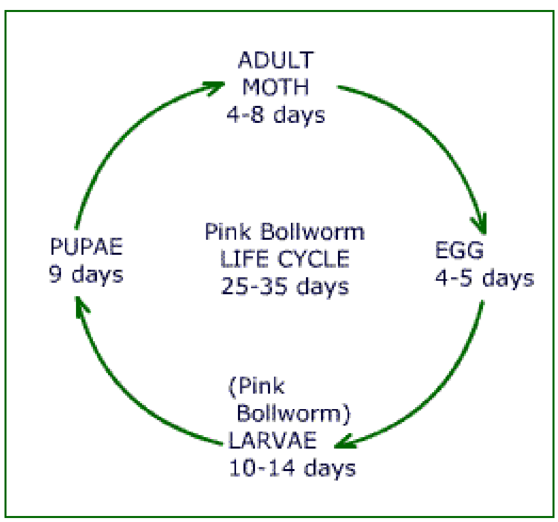
However, India may not be the centre of origin of these species because about 20 related species live in Australia on malvaceous hosts such as wild *Hibiscus*.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

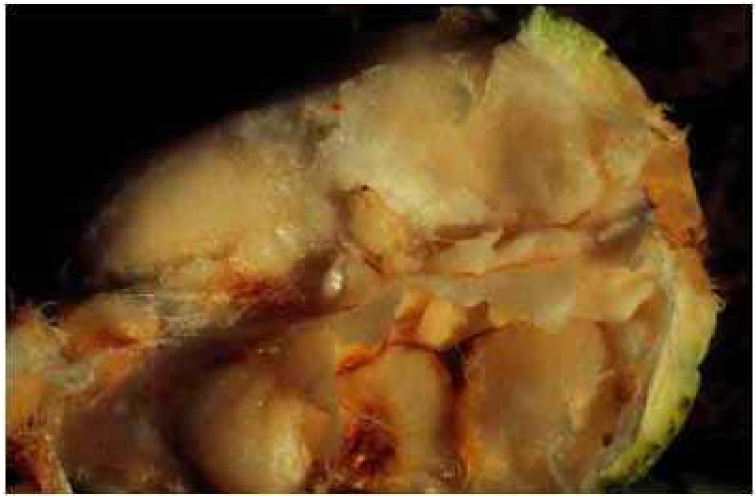
Description of life stages

The eggs are white when laid and then darken through yellow until they are orange or red before they hatch. They have a flattened oval shape and measure 0.5 x 0.25 mm across their base. The sculpturing is in the form of longitudinal lines.

The neonate larva is 1 mm long with a white body. By the time it has reached the 3rd instar, it is 6 mm long. It has two pink stripes on each body segments, still on a creamy white background., unless it is feeding flowers. In this case it remains white. The final instar (usually the fourth) is 15 mm long.



There is a young pink bollworm larva in the middle of the picture below.



Note the pink bollworm pupa in the damaged boll pictured below.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Biology of life stages

Eggs

The egg stage lasts 3.5 -6 days in the field. The females lay them singly or in groups of four or five. If there are no bolls on the plant the are placed in leaf axils or on the underside of young leaves. Once bolls are present, they are laid on the boll or on the stalk - especially in various nooks and crannies around the bracteoles etc.

Larvae

The larval stage lasts 9-20 days depending on the temperature. Development can be completed in one bud/square unless it falls off the plant (dehisces) in less than 10 days.

Larvae cause bud shedding, flower damage, loss of smaller bolls and partial damage to larger bolls. Damaged bolls are difficult to harvest because they do not fluff out. The amount of lint is reduced and is of poor quality. Exit holes permit the penetration of the contaminant fungus.

This species produces a lot of webbing. When they feed on buds they often 'wrap them up'. The flower becomes distorted when the bud opens. This 'rosetting' is an early indication of an attack by PBW.

Larvae are either short cycle (they pupate and turn into moths without any break) or long cycle (they pupate and enter a resting phase (diapause link) before emerging as moths).

Short cycle caterpillars cut a round 2 mm diameter exit hole through the carpel wall of the boll, emerge and pupate on the ground, or they tunnel to the cuticle of the boll, cut a window and pupate in the boll, from which they emerge as moths. The fully grown caterpillar spins a loose coccon with an exit window for the prepupa - which lasts 2.5-3.5 days. The shiny brown pupa is 6-8 mm long and 2.5 mm wide and lasts 8-13 days in equatorial regions.

Long cycle caterpillars spin a thick walled, tightly woven spherical cocoon or 'hibernaculum' in which the larva curls up and pupates. It emerges weeks or months later as a moth. The long cycle larvae are associated with the end of the cotton crop. Not all larvae in a generation enter diapause. The mechanism and stimuli are not fully defined, except to the extent that a long diapause is induced by high fluctuating temperatures and short decreasing photoperiod.

Prepupae and Pupae

The larva spins a cocoon and rests for 2.5-3.5 days in the prepupal stage. The shiny brown pupa (6-8 mm long and 2.5 mm maximum width) can be seen in the cocoon. The pupal stage lasts 8-13 days if it does not enter diapause (short cycle) .

The exit holes in the bolls allow a fungus Aspergillus flavus to penetrate the boll and contaminate the lint. The disease symptoms, pink-brown discolouration, develop after the caterpillar has vacated the boll. This is of importance when the seed is extracted for oil because the fungus can release a mycotoxin - aflatoxin - into the oil (and cake) that can induce liver cancer in mammals and birds.

Adults

The moths are grey brown with blackish bands on the forewings. The hindwings are silver- grey. The body is 8-9 mm long and the wing-span 15-20 mm. They emerge from the pupal skin in the early morning and mate after dark. Males mate about four times and females twice. Approximately 80% have mated by the end of the second night. A female lays 100-500 eggs. Moths live from 5 to 31 days in captivity. They can be attracted to mercury vapour lights. They will feed artificially on sugar water, dilute honey, water and molasses mixed in beer.

Post emergence flights are local and distant. They are capable of extensive flights. They have been found at altitudes of 1000m and are able to infest cotton fields separated from other areas by as much as 100 km.

Hosts

All cotton species, Lady's finger, okra etc. *Abelmoschus* spp, including kenaf (*A. cannabinus*), roselle (*A. sabdariffa*), *Corchorus olitorius* (jute).

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Management options

Economic status

Pink bollworm is a major bollworm pest in the North Africa and West Asia. As such, it is the reason for a significant amount of the pesticides applied to cotton. Its importance seems to decline as we move eastwards. Although this is not a static situation. Feed back from participants in this course would help elucidate the current situation. The importance of this species is viewed in terms of:

- the reduction in the yield and quality of the lint
- the cost of the pesticide input, and
- the additional effects of the pesticides as they extend beyond the management of the pest.

Pheromones

The sex attractant pheromone of this species was subject to intensive research in the 1970s and 1980s and the successes formed a firm basis for subsequent progress with other species. The male attractant is commercially available as gossyplure, dispensed on rubber septa, that remain active in the field for about one month. Many trap designs have been tried, but delta tunnel traps are probably best in terms of efficiency, price and ease of application.

Such traps are suitable and necessary for monitoring flights and are employed as a standard practice in many parts of the world. In southern California insecticides are not applied for PBW control until moths catches reach 12-15 moths per trap in early to mid season and 3.5 - 4 moths per trap in late season.

However, there are further applications of pheromone technology. Exercises first carried out in Egypt demonstrated that saturating the air in and over cotton fields with pheromone masked the natural emissions of the females and confused the males. Female moths remained unmated (mating disruption). Mating disruption exercises involving PBW and Helicoverpa pheromones have proved successful in Israel. Male moths can also be attracted and killed when the pheromone is added to a gel containing a suitable insecticide such as cypermethrin. This technique has successfully been tested in India.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Management options

Host plant resistance

Cotton genotypes with the following characters are less susceptible to attack by PBW:
In an American upland background - nectariless, nectariless - glabrous, okra leaf, super okra leaf, densely pubescent, high gossypol, internal boll antibiosis, early.

Significant levels of resistance has been demonstrated among certain hybrids in China. Further information about locally adapted varieties should be sought from the appropriate research institutions.

Cotton transformed with the Bacillus thuringiensis gene Cry 1 Ac gene have proved to be resistant to PBW in on-farm conditions in USA and Israel. No resistance to Bt cotton has been reported, although it has been induced in laboratory conditions. Bt cotton also has considerably lower levels of the aflatoxin that results from the infections of bored bolls by *A. flavus*.

Insecticides

Action thresholds adopted in the USA are based on the number of rosetted flowers and percentage boll infestation - apply an insecticide when 20 of 100 bolls, collected at random from a given tract, are infested with a larva. These are based on the economics of cotton production in USA and would have to be revisited in the context of Asian production systems.

A review of the literature indicates that most insecticides that are active against lepidopterous pests have provided a satisfactory degree of control of PBW in field conditions. However, we need to think about what we know about the life cycle of this species and be somewhat strategic. For instance, we know that the larva spends most of its time inside a boll. Therefore, we need to target the eggs and neonate larvae. This means that materials with ovicidal action are called for. We also know that the eggs are often hidden away in nooks and crannies of the plant so that cover must be good and a good wetting agent should be included in the formulation. As eggs and neonates are the target, IPM practitioners would recommend a low dose of a soft insecticide in the hope of preserving the populations of natural enemies.

Some points

- Apply a low rate of an insecticide that will not disrupt natural control processes, such as lufenuron, timed to precede the emergence of the first batch of eggs.
- Repeated applications of the same insecticide class have led to outbreaks of spider mites, and Helicoverpa.
- Pyrethroids have been successful control agents in the past, but as high levels of resistance have been detected in China, they should be considered with circumspection as a late season 'clean-up' remedy.
- Adopt an attract and kill approach, if these products are available on local markets.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Management options

Natural Enemies

Beneficial species include:

- Ground beetles and rove beetles as pupal predators.
- Egg and egg/larval parasites such as Trichogramma, Bracon spp. Apanteles spp and Chelonus.
- Egg predators such as ladybirds, flower bugs (anthocorids), and lacewings (Chrysoperla).
- Nematodes are under investigation in the USA. They are effective but the economics of the process and the success of scaling up are not known.

Several attempts at biological control have been attempted in different parts of the world, with varying degrees of success (in the range 'none to partial'). It should be noted that the beneficials associated with the management of PBW are part of the natural fauna of tropical agroecosystems so that it can be assumed that if their activity is either:

- enhanced - at the best (e.g. by increasing the diversity in the crop environment), or
- not interfered with too much - at the worst (by applications of selective or low dose insecticides).

Natural control processes combined with the cultural management methods suggested will suppress the problems created by PBW.

Cultural Control

The following (area-wide) practices have been adopted with success in many parts of the world:

- Ensure a long close season when no cotton or alternate host is cultivated. Avoid the temptation of a ratoon crop.

- Cultivate after harvest.
- Destroy alternative hosts in the vicinity.
- Burning crop residues is the most effective method of dealing with residual populations, but this may not be acceptable in terms of the overall management of the farm.
- Destroy pupae and long-term larvae lodged in the post-season trash by thorough cultivation and destruction of the crop residue by mob stocking with sheep and goats.
- Where stalks are used for fuel, stack them 2 m high facing W and S. Farmers should be dissuaded from this practice if possible.
- Intercrop and rotate cotton with non-host species.

Cotton grown with a plastic mulch had increased PBW attack in China. Mulching increased the number of eggs by a factor of 3.4 and doubled the number of second generation larvae.

Pink and Pink-spotted Bollworms (*Pectinophora* spp.) Reference

Management options

Putting it all together - Pectinophora IPM

Farmers need to become familiar with the local pattern of flight activity by monitoring the flight activity of moths. A pheromone trap can be placed in the field and checked daily. This information will, over a number of seasons, indicate when farmers need to be most vigilant and whether there are PBW-free periods that can be exploited.

The PBW life cycle offers clues to successful management strategies:

- Larvae are susceptible to insecticides and natural enemies for a short time (2h) while they penetrate buds, flowers or bolls. Pheromone trapping will tell us when to apply a pesticide to ensure that the newly hatched larva comes into contact with a toxic residue
- Eggs are available (to an ovicide) for longer and are fully open to attack by predators and parasites.
- Pupae are located in or on the soil and are prone to predation or can be damaged by cultivation. Some long cycle pupae remain in the plant and soil after harvest.
- The adult is a difficult target because of its ability to disperse so effectively, however, it can be attacked through mating disruption and lure and kill techniques.

Aphids Reference

Taxonomic Identification

Order: Homoptera:Hemiptera
Family: Aphididae

There are several species of aphid that can live on cotton plants. Only Aphis gossypii Glover is of widespread importance. This species has created considerable interest among taxonomists - some 50 synonyms and/or subspecies were listed as long ago as 1976.

Distribution and host plants

The cotton aphid is present in all tropical, sub-tropical and warm temperate regions of the world. It can probably attack cotton wherever it is grown. This species is equally well known as a pest of leguminous and cucurbitaceous field crops and of glasshouse crops in general. It is considered to be omnivorous as it has so many wild and cultivated hosts.

Aphids Reference

Description and biology of life stages

This aphid is extremely variable in colour. The members of one colony can be brown-green, grey green, dark green, or blackish brown. It can also be yellow, brown with green marbling, orange-yellow, lemon yellow, ochre, or white. There are also size variations. This variability probably explains why so many sub-species have been described.

As with most species of aphid there are two forms - the wingless (apterous) and winged (alate) forms.

The wingless forms produce live young. They are characteristic of a stable environment where the aphids have plenty of 'space' to expand into and where there is little environmental challenge.

The winged forms appear when the environment of the aphids exerts some pressure - for instance deterioration of the host plant quality, high aphid density, and low temperatures. In some species males occur and fertile matings result in egg deposition.

The whole subject of aphid life cycles is complicated - especially in the genus *Aphis*. For our current purposes we need to know that the complexity exists but need not become involved with the details.

The two forms have different morphology as can be seen with the help of a hand lens or low powered microscope.

The wingless or apterous form: This form has no sign of any wings or wing buds. The antennae have six segments (occasionally 5) and have dark tips and bases.

The winged or alate form: The adults have wings and the nymphs have wing buds. The head, antennae and thorax have dark pigmentation ('smoky').

The optimum temperature for development is between 25 and 30ºC. Nymphal development takes only 4-6 days at this temperature. A 'mother' lives for about two weeks and can produce 80 nymphs during this period. Although there is variation according to biotype and the physiology of the host, it is very clear that the life strategy of aphids is to colonize a given environment rapidly and then disperse via the formation of the winged forms.

Aphids Reference

Population dynamics

A. gossypii is a good example of an r-strategist.

The main predators of the cotton aphid are ladybirds, lacewings, syrphids and anthocorids. However, ground living spiders and insects, such as ground beetles (carabids) and rove beetles (staphylinids) may also hunt in the foliage during the night and will almost certainly 'browse' on aphids.

Parasites of *A. gossypii* are known but have little impact on the population density of this species.

Rain is an important mortality factor because of its physical effect on aphid colonies and because it creates the environmental conditions that promote the development of entomopathogens (insect diseases), in particular fungal diseases. Diseased aphids appear pink or white as a result of a coating of fungal spores. Excessive application of fungicides can promote aphid outbreaks by killing the fungal pathogens of aphids.

Ants: aphids get rid of the excess liquid they produce in the form of honeydew - small droplets of dilute sugar solution. As indicated above this contributes to the damage they can cause to cotton, but it also attracts ants and is a major energy source of the colonies of some species. The generally held view is that ants protect the aphid colonies from predators in exchange for the honeydew.

This brings forward a strategy conflict within an IPM program for cotton. Ants are seen as important bollworm predators on the one hand but, when aphids are around, they may repel predators.

Aphids Reference

Management options

To generalize - in most cotton tracts aphids were not considered to be a pest until intensive insecticide regimes were implemented in the early 1980s. Since that time their importance has increased throughout Asia and in the West Africa/North Asia area. There have also been widespread reports of insecticide resistance.

With this knowledge in mind the strategy in Australia, for instance, has been to suggest that farmers live with (accept) a little damage and delay spraying a conventional insecticide until significant levels of Helicoverpa oviposition are detected.

In South Asia the practice of seed treatment with a neonicotinoid insecticide is common. This effectively keeps the plant clear of sucking pests for the first 30-40 days. However, it also reduces the attractiveness of the plant to the natural enemies of the pests (because there is no prey for them to eat) so that additional measures are needed. This involves sowing an intercrop of cowpea or another legume crop species that will attract *Aphis craccivora* (not a cotton pest) and large numbers of ladybirds and other aphid predators. The legume crop can be harvested after 60-70 days for a cash return or family food. The ladybirds disperse into the cotton after about 50 days after sowing - as the legumes mature and become less attractive to aphids.

Insecticides

Where outbreaks of aphids and sucking pests are anticipated, seed treatment with a neonicotinoid insecticide will provide 30-40 days protection during the seedling stage. Most Class III materials are effective against aphids, provided there is no resistance. There are also a number of selective aphicides that have little or no impact on the predators.

Insecticide resistance management

If seed treatment has been carried out, no further treatment for aphids will be needed. A single treatment by seed dressing is unlikely to create resistance. However, further applications of the same, or a similar material, as a foliar spray should be restricted to one or two per season to ensure the conservation of this important group of insecticides. Excessive or repeated application of a single material for bollworm control can lead to resistance-associated outbreaks of other pests including aphids.

Insecticide resistance has been detected in this species so pest managers need to be aware that certain insecticide classes may have little effect on aphids when applied for bollworm management. They should make a note of which classes of insecticide do not kill aphids for future reference.

Cultural Control

Cultural practices that discourage aphid proliferation and subsequent sticky cotton are:

- Maximize row width.

- When applying nitrogenous fertilizers, tend towards less rather than more. Urea, DPA, etc. stimulate aphid populations.
- Restricted irrigation after bolls open.
- Frequent pickings.

Jassids (Leaf hoppers) Reference

Taxonomy and Distribution

Order: Homoptera:Hemiptera
Family: Cicadellidae

Amrasca devestans Distant (also known as *A. biguttula* or *Empoasca devestans*) the Indian cotton jassid, is the major concern across Asia. In Africa, *Jacobiasca lybica* and *J. fascialis* are the dominant jassids. *Empoasca terrae reginae* is found on cotton in Queensland, Australia.

Description of life stages

The egg is inserted into a tender stem, petiole or the mid-rib or a large vein on the top or bottom of a leaf. The average length is 0.7-0.9 mm and the width 0.15-0.2 mm. The nymphs are active frog like insects that run sideways. They have a frog-like appearance and are yellow-green. They are usually on the lower sides of leaves, but have a strong tendency to attempt to hide when disturbed. The adults grow to 2.5 mm in length. They are pale green with fine membranous wings. The fly or 'hop' when disturbed.

A generation is complete within 3 to 4 weeks.

Jassids (Leaf hoppers) Reference

Management options

Economic status

Cotton varieties with hairy leaves are less susceptible to jassid attack than varieties with shiny (glabrous) leaves. The benefits of either a resistant variety or an effective insecticide program have been estimated to be 250 kg lint/ha or a reduction in loss from 25 to 12%.

Jassids inject a toxin into the plant. This causes yellowing and reddening of the leaf (hopper burn), cupping (an inward curl of the leaf), and leaf fall. In severe cases the vigour of the plant is diminished and it does not grow. Jassid attacks start early in the season. They become less important as the crop develops - but persist throughout the season.

Host plant resistance

There are very high levels of correlation between the density of leaf hairs (longer than 3 mm) and susceptibility to jassid attack. So in areas where bollworms are not a problem and jassid resistant varieties are available farmers would be advised to grow them.

Insecticides

Jassids are susceptible to low rates of most insecticides. However, they are suppressed by neonicotinoid insecticides applied as a seed dressing. Early season insecticide applications specifically for jassid management are discouraged to conserve natural enemies unless the density exceeds two adults or nymphs per leaf on hairy varieties or one per leaf on non-hairy varieties. This threshold has proved effective in Asia and Africa.

Natural Enemies

Nymphs are caught by the faster moving natural enemies - such as spiders and anthocorids. The latter also eat the eggs. Egg parasites (e.g. Anagrus empoascae, Stethynium empoascae and Arescon enocki) have been reported from South Asia but information about their distribution and abundance is lacking.

Spider Mites Reference

Nomenclature and distribution

It would be easy to get enmeshed in detail when dealing with the complex of mites living on cotton plants. Members of three superfamilies are said to be cotton pests worldwide. Of these, one family, the Tetranychidae gives us 36 potential pest species, 9 of which are potentially serious. There are two genera of note:

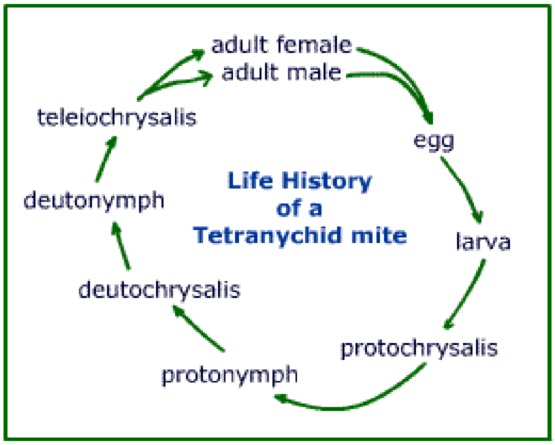
Tetranychus, which colonizes the lower leaf surface. These are the true spider mites and the ones we have to focus on. The feeding punctures can be seen through the lamina as whitish areas. Members of this genus are pandemic on cotton and virtually all other kinds of cultivated plant. Tetranychids are bright red when seen through a hand lens or stereo-microscope and never exceed 0.5 mm in length.

The species of *Tetranychus* found in the Asia-Pacific Region are: *T. lombardini* Baker and Pritchard, *T. ludeni* Zacher, *T. macfarlanei* Baker and Pritchard, *T. marianae* McGregor, *T. neocaledonicus* Andre, *T. peirci* McGregor, and, in cooler areas, for instance in China, *T. urticae* Koch and its 'form' *cinnabarinus* Boisduval.

The greatest diversity of pest species is in Africa. This includes the other *Tetranychus* spp., and *Oligonychus*, which colonizes the upper leaf surface. This genus is restricted to Latin America and tropical Africa.

Life Cycle and Biology

The life cycle is made complicated by the name given to the various stages (see box). In essence, there are three active stages (in bold) between egg and adult and these alternate with 'resting' stages (in italics). At 25 ºC the life - cycle egg to adult - on cotton takes 9 days. A female can live up to 30 days at this temperature and lay as many as 100 eggs. Thus the rate of reproduction is pretty fast.



Dispersal: spider mites can get carried around by other insects (phoresy), humans and on farm equipment. However, the more natural process is of 'ballooning'. The young adults move to the edge of their leaf and secrete a thread of silk. This catches the breeze and they float off and land wherever the wind takes them.

Management Options

Economic status

Spider mites feed on the lower surface of leaves. They make a fine protective webbing which is often more conspicuous than the mites. They suck out the epidermal and mesophyll cells. This causes the leaf to dry and buckle. The top of the leaves turn brown - bronzing - and defoliation follows.

Spider mite infestations usually start later than aphid and jassid attacks. Reports from around the world indicate that spider mites can cause in excess of 50% reductions in the anticipated crop yields. This reflects both reductions in lint weight, lint quality and seed number. The earlier the attack starts the worse the crop loss.

However, mite attacks do not usually occur spontaneously. They often follow heavy applications of fungicides and/or insecticides that have been applied in response to other pest species.

Insecticides/Acaricides

Spider mites are susceptible to many insecticides and some fungicides. However, their rapid reproduction rate means that resistant strains can appear within a season if a particular class of pesticides is applied repeatedly.

Natural Enemies

Spider mites have an extensive range of predators. Apart from anticipated groups, such as ladybirds, lacewings, and anthocorids, thrips (e.g. *Frankliniella vespiformis*), cecidomyiid midges and other types of mite (Phytoseiidae) are also important. The latter are of considerable interest because there are strains that are resistant to insecticides. They have been reared and released in environments where mites are pests but where specific insecticides are needed for the management of other pests. This approach remains to be attempted in cotton crops.

Cultural Control

None known.

Thrips Reference

Nomenclature

There are two suborders of thrips (Thysanoptera).

Terebrantia: females have an ovipositor for egg laying.
Tubulifera: the 10th abdominal segment of females forms a tube through which eggs are deposited.

Many species of thrips have been found on cotton plants around the world. It appears that none have a particular preference for cotton, but the following species are general feeders, worldwide, frequently found on cotton and associated with crop (foliage) damage.

Thrips tabaci
Thrips palmi
Frankliniella schlutzei
Frankliniella occidentalis
Caliothrips impurus

Megalurothrips spp. lives in flowers and can cause superficial damage.

Description and biology of life stages

Thrips do not offer much morphological variation to assist in their identification. This means that characteristics such as hair patterns and the number of 'cilia' along the fringes of the hind wing play an important part. For this a good compound microscope is required, together with the facilities needed to prepare microscope slides. Thrips taxonomy is a specialist job. However, good keys exist, so a person with the appropriate facilities who is interested in thrips should not be deterred. Talk to your tutor.

Adults are slender and 1.0-2.5 mm long. They have two pairs of wings. These are diagnostic of thrips because the wings have a fringe of fine 'hairs' or bristles (cilia) instead of a membrane. Thrips are member of the order Thysanoptera. This name is derived from the Ancient Greek words for 'fringe' and 'wing'.

The head has two compound eyes and three simple eyes (ocelli). The mouthparts are adapted to form stylets, which are extended to penetrate plant tissue. The abdomen has 10 segments.

The colour varies according to the species. Megalurothrips for instance is shiny black. Thrips spp. are cream-yellow.

Eggs are large when compared to the size of the adult: 0.2-0.3 mm long and 0.1 to 1.5 mm wide. They are either kidney shaped or ellipsoidal according to the sub-order.

There are two larval stages, which are whitish and wingless, but are otherwise similar to the adults. They are active feeders.

There are two or three 'nymphal' stages (according to the sub-order). They are sometimes called pupae because they do not feed. They can be recognized because they have wing buds developing on the thorax.

Terebrantia (those with an ovipositor) insert their eggs, one at a time, beneath the epidermis of a leaf. Tubulifera, which lack the ovipositor stick their eggs in groups of 3-5 on the leaf surface. A female will lay 30-100 eggs over a period of up to 30 days.

The larvae feed on the cell contents (rather than by 'tapping into' the phloem or xylem) of the parenchyma of young leaves. This kills groups of cells, which initially have a white appearance. As the leaf expands the groups of cells become lesions and splits in the leaf that do not expand at the same rate as undamaged cells. This uneven growth explains the leaf distortion characteristic of thrips damage.

The larval period can last about two weeks or less depending on the temperature. 'Pupation' takes place in the soil in many species. The inactive nymphal stages lasts about three days. The adults emerge and resume the same kind of feeding activity as the larvae.

Thrips are capable of long flights. This statement could be modified to: 'Thrips can be carried over long distances by the wind'. The point is that, though small, thrips are effective colonizers of new habitats by virtue of their ability to be carried as 'aerial plankton' on air currents.

Management Options

Economic status

Thrips colonize crops early in the season. They can cause serious feeding damage to seedlings and young leaves as shown in the picture above. The nature of the injury is described below.

Insecticides

Thrips are susceptible to all the conventional insecticides that are likely to be applied to cotton. Most significantly, a seed treatment of a neonicotinoid material will suppress population development during the critical seedling and early vegetative stages.

Natural enemies

The most potent predator of thrips is another thrips species - *Frankliniella vespiformis* - but all the other predaceous insects and spiders will eat them. Eulophid and Trichogrammatid egg parasites will be found where insecticide application has been restricted.

Sweet Potato Whitefly Reference

Taxonomy and Distribution

Order: Homoptera:Hemiptera
Family: Aleyrodidae

The main whitefly pest of cotton is *Bemisia tabaci* Gennadius, the sweet potato whitefly. It has about 15 synonyms. There are also a number of biotypes - including the so-called B strain. Studies of the DNA structure indicate that the B strain may be a different species. It is sufficient for our current purposes that we recognize that it is physiologically different to the 'regular whitefly' to the extent of being able to develop rapid resistance to insecticides.

Members of the genus *Trialeurodes* are less important pests of cotton in the USA and in NE Africa.

B. tabaci is likely to be a pest of cotton and many other crops in all tropical and sub-tropical climes where cotton is grown.

Description and biology of life stages

The female is 1.1-1.2 mm long and the male slightly smaller. The bodies are pale yellow and both pairs of wings are white. The sexes can be distinguished under a microscope or strong hand lens. The female's abdomen tip is rounded, while the male's is more slender and pointed.

Parthenogenesis: fertilization is not necessary for the production of fertile eggs, but parthenogenetically produced eggs are male. The female takes 1-8 days to develop eggs at temperatures between 22 and 26ºC. Eggs are ellipsoidal and laid on the underside of leaves in the upper parts of the plant. They are inserted through the epidermis into the mesophyll so that the long axis is vertical to the epidermis. Reports of fecundity vary from maxima of 40 to 300. Eggs hatch in about 8 days at 25ºC. Adults live for 10-12 days in laboratory conditions.

There are three nymphal instars (sometimes wrongly called larvae) and a (so-called) pupa. First instar nymphs are yellow and become yellow green as they proceed to their final moult. They have colourless waxy coating. The antennae, mouthparts and legs are on the underside. Pupae are yellow to brown with crenulated (wavy) margins. In other words, the immature stages are not particularly interesting to look at - they have the appearance of green, yellow or brown shields stuck onto the underside of leaves.

Development from egg to adult takes about 20 days so that birth to death is about 1 month. Fecundity is fairly high. Thus whitefly are more 'r' orientated than 'K'.

Initial infestation of a crop comes early in the season from literally hundreds of cultivated and weed hosts. Unlike aphids, for instance, infestations can last through the whole cropping season. In fact, late season attacks often seems more intense than those in the seedling stage - this could be attributable to what?

Whitefly is not recognized as being a strong flier but, like all small insects, it can be carried long distances on wind currents. Crop infestation is thus likely to be from from local sources. The nymphs can move around a little but they are not noted for their movements around the plant.

The adults flit around readily when disturbed. An infestation is easily detected by gently shaking a plant - the small white insects fly around briefly - a matter of metre or so and then resettle.

Management Options

Economic status

The damage caused by whitefly is similar to that caused by aphids:

1. Debilitation of the plant caused by the feeding of thousands of insects plugged into the vascular system. The illustrations show that these insects can achieve extremely high densities. Leaf sugar and nitrogen levels are measurably lower on heavily infested plants than on lightly infested plants. This undoubtedly has a negative effect on boll size and lint quality.
2. Contamination of the upper leaf surfaces and lint with honeydew and then sooty moulds.
3. Transmission of viruses such as cotton leaf crumple and cotton leaf curl.

Thus, of all the sucking pests of cotton, these insects are the most feared - especially because of the apparent ease with which they develop resistance to insecticides. Their economic status has increased since the early 1980s. This is believed to be because the use of broad-spectrum insecticides reduced the population density of the natural enemies that previously kept whitefly in some kind of check.

These insects are not easy to manage because they can reproduce quickly, do not move around very much (what is the significance of this in terms of insecticide application?) and because they are located almost exclusively on the underside of leaves. The waxy coating of the immature stages probably also causes spray deposits to run off. They are receiving considerable attention from the world scientific community in terms of developing integrated control programs. It is anticipated that this information will be made available here as it becomes accessible.

Insecticides

Seed treatment with a neonicotinoid insecticide has a suppressing influence on whitefly for 30 days. However, after that, populations may build up unless natural enemies are present in numbers or a suitable, selective insecticide is applied.

Satisfactory insecticidal control with conventional insecticides is not easy to achieve (above) because colonies can spread into the lower parts of the plant and are nearly always on the lower sides of leaves. Their immobility and their waxy coating create further difficulties in terms of the optimisation of spray technology.

Natural Enemies

Successful biological control programs for whitefly in glasshouses are based on the release of Encarcia Formosa, an aphelinid parasite. This species - or, more precisely, the species complex - has a marked impact on whitefly in the field to the extent of reducing whitefly population densities by >50% in some cases. The process is density dependent (see box) which means that high, perhaps damaging, population levels have to be in the crops for parasitism to maximize.

Whiteflies are subject to predation from a large number of species - ladybirds, anthocorids, lacewings, phytoseiid mites and more. See text below for more on whitefly parasites in USA.

Cultural Control

Whiteflies spend their lives 'tapped' into a plant. This means that they are intimately associated with what is happening to the physiology of the plant

Cotton Weeds Reference

Management Options

Successful weed management in cotton is founded on the preparative activities undertaken when the crop is not in the ground:

- Post harvest clean up (see also Helicoverpa and pink bollworm) to bury crop trash and weeds as deeply as possible.
- Preseason cultivation for weed control and seed bed preparation.
- Rotation e.g. with wheat as the practice in Pakistan, or a legume as in southern India. The choice of the rotation crop can be made to permit an alternate herbicide regime. For example a herbicide that kills broad leaf plants only can be used for Amaranthus control when a wheat crop is in the ground.
- Fallow combined with tillage and herbicides in the case of heavy infestations of perrenial grasses.
- Application of a herbicide before sowing or before seedling emergence (table).

Once the crop is growing:

- Hand-weeding can be employed if labour is available and economic. Thinning and weeding usually go together so that at least one pass between the rows should be possible.
- Intercultivation, with a bullock and plough or with a tractor drawn implement (e.g. a disk cultivator), are possible if the sowing pattern permits. This procedure requires accurate sowing and tractor work.
- A number of selective herbicides are available for careful spot treatment once the crop has emerged.

No reports of successful biological control programmes for cotton weeds per se have been encountered.

Caution in the use of herbicides

Farmers should be cautioned against attempting to completely eliminate the weeds in and around their fields with herbicides.

Weeds are a source of fodder and a reservoir of the natural enemies of insect pests. They hold the soil and therefore prevent soil loss, especially in water channels. Excessive application can lead to the accumulation of residues which can have unwanted effects on future crops in the rotation.

Doubts about the compatibility of a particular herbicide with the cotton crop can be checked by spraying a small area before an extensive application is made.

Table: Some herbicides that are compatible with cotton cultivation

Herbicide	**Pre-emergence**	**Before sowing**	**Post-emergence**
Butroxydim			Y

Dicamba	Y		
Diuron	Y	Y	Y
DSMA			Y
Fluazifop			Y
Fluometuron	Y	Y	Y
Fluometuron+prometryn	Y	Y	Y
Glyphosate	Y		Y
Haloxyphop			Y
MSMA			Y
Norfluazon	Y		
Paraquat	Y	Y	Y
Paraquat + diquat	Y	Y	
Pendimethalin	Y	Y	
Prometryn	Y	Y	Y
Propaquizafop			Y
Pyrithiobac-Sodium			Y
S-Metolachlor	Y	Y	Y
Triclopyr	Y		
Trifluralin			Y
Sethoxydim			Y
2,2,DPA			Y

Label information should be followed and advice should be taken from appropriate experts about local conditions before advising farmers about the use of these and other herbicides. Each has a special application and unique characteristics.

Cotton Diseases Reference

Diseases of cotton in Asia's major production countries

Pathogen	**Disease/Common names**	**Pakistan**	**India**	**China**	**Australia**
Xanthomonas spp	Bacterial blight orblack arm, angular leaf spot	++	+	-	+
Cotton leaf curl virus (vector = whiteflies)*		++ (Punjab)	++ (Punjab)	-	-
Bonsai Bunchy Top Disorder (vector = *A. gossypii*)*		-	-	-	+
Tobacco streak virus	Cotton mosaic virus	+	-	-	-
Rhizoctonia solani	SDC** Damping off	+	-	+	-
Alternaria spp	Leaf spot	+	-	-	-

Verticillium spp	Verticillium wilt	-	-	-	+
Colletotrichum gossypii *C. indicum*	Anthracnose Boll rot Boll rot	- - -	- - +	+ + -	- - -
Fusarium spp	Wilt Blight? Boll rot?	- - -	- - -	+ - -	- - -
Macrophomina phaseolina	Root rot	+	+	-	-
Schlerotium rolfsii	Root rot	-	+	-	-
Myrothecium roridum	Boll rot	+	-	-	-
Aspergillus spp	Boll rot	-	+	-	-
Meloidogyne incognita	Root knot nematode	+	+	+	+

++ - important, + = present, - = not recorded (this does not necessarily mean absent')

* Details in Sucking Pests section,
** SDC = part of seedling disease complex, *Pythium* spp, *Fusarium* spp, *Xanthomonas*, and *Glomerella gossypii* may also be part of the complex.

Some notes on the most important diseases

Nematodes and Fusarium: The root knot nematode - it interferes with root function by forming galls on the roots - is pandemic. Fusarium wilt is nearly always associated with nematodes.

Symptons of Fusarium wilt: leaves wilt; yellowing and necrosis of leaves [69K] begin on the leaf margins. Internally, xylem [78K] is dark brown in colour. Plants attacked early are extremely stunted. Root knot nematode galling [54K] is normally prevalent on lateral roots of affected plants.

Verticillium wilt: Leaves wilt and show interveinal yellowing [70K] before becoming necrotic. Light to dark brown vascular discoloration [41K] is prominent in the stem and branches. Defoliation and death of plants may occur. Disease severity depends on the number of root penetrations. Verticillium wilt is favoured by cool air and soil temperatures.

Bacterial wilt: This disease is widespread. Symptoms are watery lesions that dry out to irregular necrotic areas on the leaves and bolls. Leaves and bolls drop in severe cases.

Virus diseases: Looking at the world scene - two whitefly-vectored geminiviruses (the virus particles occur in electronmicrographs as paired or twinned particles - are causing most concern.

- Leaf crumple virus occurs in southwestern USA, and Latin America. The edges of the leaves on infected plants turn downwards.
- Leaf curl virus is found in Africa and Asia. The edges of leaves curl upwads.
  Plant death follows an early infection. Older plants will be impaired in terms of reduced lint production although the quality is not affected.

Leaf curl virus has been known in Africa since the 1900s. It appeared Pakistan in the 1960s but was considered to be of minor importance until the late 1980s. This change in status may have been a result of the a high yielding variety S 12 that was made available at this time. This variety has no resistance to the virus. It is suspected that genetic changes in the vector and the popularity of this variety led to the elevation of this virus from minor to major status. It has had a deleterious effect on the productivity of individual farms and on the national lint production. The virus has spread into the Indian Punjab, but no confirmed reports of a further extension of its range have been found.

Cotton mosaic virus (tobacco streak virus) is found throughout Pakistan where it is a minor problem.

These varieties are resistant to leaf curl but not to cotton mosaic:
CIM 434, 435, 443, 445, 448, 1100. LRA-5166, BH 100, FH 634, VH 53, and VH 55.

These varieties are resistant to cotton mosaic but not to leaf curl:
CIM 70, S 12, B 622, B 30, B 496, BH 4, BH 89, 94, and 95, and Krishna.

Origins of infestations

Soil: Disease propagules (spores, cysts etc.) can originate from previous infestations and stay in the soil from one season to the next. This results in the appearance of the same diseases in the fields irrespective of the rotation. Examples are *Fusarium* and *Verticillium*.

Seed: Bacterial blight and *Ascochyta*, for instance, are carried on the seed. They can be managed to some extent by a bacteriocide, such as copper oxychloride, in the case of the former and by acid delinting. Colletotrichum can be present as an internal infection. Seed treatment with a fungicide will reduce the effect of this pathogen.

Wind: Spores of fungal diseases can be carried around by the wind - in particular rust diseases - but these are not particular to cotton in the Asia Pacific region.

Humans: Nematodes live in the soil and soil is transferred easily from one place to another on feet, vehicles and farm equipment. If nematodes are important in your sphere of influence it is worth remembering this, especially if you travel widely.

Diseases of the Seedling stage (Seedling Disease Complex)

Rhizoctonia root rot (*Rhizoctonia solani*)

Rhizoctonia root rot shown above is one of a number of diseases that can kill seedlings. Other genera include *Xanthomonas*, *Fusarium*, *Pythium*, and *Verticillium*. Details of their regional importance are not easy to locate.

Management Options

Perhaps even more so than with other pests, prevention of diseases is better than cure.

The origins of the diseases will give you some clues about their management.

For virus disease management, the farmer needs to be aware of where the disease comes from - he or she should be able to link the disease symptoms with the vector and should know that virus diseases can rarely be controlled successfully by excessive insecticide application.

The farmer can keep the fungal disease complex as a whole in check by:

- Ploughing in the crop trash at the end of the season.
- Crop rotation with a cereal crop (wheat, sorghum or maize).
- Buying good quality seed that has been acid delinted.
- Treating the seed with a fungicide (in conjunction with a neonicotinoid insecticide - see sucking pests module) or applying a fungicide in the furrow or mixing it with seed in the seed box on the planter if s/he has one.
- If foliar disease lesions are present a prompt application of a fungicide spray could turn around an incipient attack. However, the investment in the fungicide may not pay off if harvest is likely to be complete with 20-30 days.
- Boll rots follow bollworm attack. The information is available in the bollworm, Earias, Pink bollworm and Helicoverpa modules.
- Some farmers may be interested in trying 'microbes' (usually other fungi) that are antagonistic to pathogenic fungi. Trichoderma is one such fungal antagonist.
- If information is available the IPM practitioner can bring forward ideas about resistant varieties in disease hot-spots.

Links

Verticillium wilt
http://www.ipm.ucdavis.edu/PMG/r114100211.html

Fusarium wilt
http://www.ipm.ucdavis.edu/PMG/r114100311.html
http://plantpathology.tamu.edu/Texlab/Fiber/Cotton/cfw.html

Nematodes
http://www.griffin.peachnet.edu/caes/cotton/97/dn_control.html

Seedling diseases
http://www.ces.ncsu.edu/depts/pp/notes/Cotton/cdin1/cdin1.htm

Bacterial blight
http://www.ces.ncsu.edu/depts/pp/notes/Cotton/cdin3/cdin3.htm
http://plantpathology.tamu.edu/Texlab/Fiber/Cotton/cbb.html

Virus diseases
http://ag.arizona.edu/pubs/crops/az1006/az100610f.html
http://web.utk.edu/~extepp/pubs/cot-dis.pdf