CHAPTER 3

PEST AND DISEASE CONTROL

Namibian Organic Association
Enabling Sustainable Organic Agriculture

IFOAM SOUTHERN AFRICAN NETWORK

german cooperation
DEUTSCHE ZUSAMMENARBEIT

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PEST AND DISEASE CONTROL

"A pest starves on a healthy plant"
Pests shun healthy plants. Pesticides weaken plants. Weakened plants open the door for pests and disease. Hence, pesticides precipitate pest attack and disease susceptibility and induce a cycle for further pesticide use.

This is the essence of the Trophobiosis Theory, a thesis presented by Francis Chaboussou, an agronomist of the French National Institute of Agricultural Research (INRA), after 50 years of researching the relationship between plants, pests and diseases (Francis Chaboussou – "Healthy Crops: A New Agricultural Revolution").

3.1 Prevention

3.1.1. Preventative methods

Proactive/Preventative pest management

Successful organic farming requires a whole-farm approach. This means managing a crop or animal as an integral part of the farm system rather than in isolation.

Substitution farming

Good organic farming is not just a matter of substituting an organically acceptable input for a synthetic chemical. Initially some farmers convert to organic farming by using allowable organic inputs to replace chemicals. This is called substitution farming and it is seen as the first step in the process of developing high output, low input organic systems. It is very useful for many conventional farmers to take this approach as it is not such a great paradigm shift from their current practices.

Move to whole-systems approach

The best organic farmers redesign their farming system so that it has a series of integrated systems that prevent pests and diseases and to give the crop a significant advantage.

The aim is to have a whole-systems approach that results in a resilient low input, high output farm. This is where ecological sciences are applied to agriculture to produce systems that fit within the paradigm of agro-ecology.

Eco Functional Intensification (EFI)

Eco Functional Intensification (EFI) is the process of setting up an integrated agro-ecological farming system.

IFOAM defines it as such:

"As an ecosystem-based sustainable production system, Organic Agriculture (OA) relies on the utilisation of biodiversity and the optimal utilisation of ecosystem services. The use of these services is the key to the success of OA. To maximise multi-functional benefits, OA utilises ecological rather than chemical intensification. Ecological intensification optimises the performance of ecosystem services.

These services include pest and disease regulation, water holding and drainage, soil building, soil biology and fertility, nutrient cycling, nitrogen fixation, photosynthesis and carbon sequestration, multiple agricultural crop and animal species, pollination and others".

Setting up natural systems to prevent or reduce pests and diseases

Biodiversity

Chemical agriculture is causing a decline in biological diversity and this is leading to a number of sustainability and environmental problems. The greater the biological complexity designed into a farming system, the less the chances for pests and pathogens to colonise and dominate that system. The aim is to create robust, sustainable bio-diverse systems with mechanisms that prevent and control most of the pest, disease and weed problems and help increase the bio-availability of nutrients. These types of farming systems do exist and require a minimum of input costs, making them the most efficient in returns to the farmer and the environment.

Soil health

Soil health is the key principle to successful sustainable farming. Correctly balanced soil ensures minimal disease and insect damage. There is a large body of good scientific evidence showing that plants growing on fertile soils are more resistant to pests and diseases than plants that are deficient or stressed due to poor soils and or poor management.

An increasing number of scientific studies show that healthy plants produce a range of compounds that prevent or reduce damage from pests and diseases, particularly the phenolic and flavonoid anti-oxidants. Interestingly, other research shows that these compounds not only protect their host plants, they are also beneficial to the health of people who consume them. These compounds are shown to have multiple benefits such as acting as an anti-inflammatory and reducing the pain associated with rheumatism, arthritis, and headaches, reducing the number of and intensity of asthma episodes, helping prevent heart disease and have anti-carcinogenic properties. Several studies show that organic foods have higher levels of these types of beneficial phytonutrients.

There is a growing body of evidence showing that healthy plants send out scent signals to each other warning of disease and insect attack and that these plants will then generate a range of protective compounds in response, and in so doing, prevent damage. Researchers are currently studying a range of compounds that plants emit when under pest attack that could attract beneficial predators to control the pests.

Many years of research have shown that well balanced soils with balanced, high levels of calcium, humus and a neutral pH encourages a range of beneficial species and suppresses pests and diseases. These soils are rich in beneficial organisms.

Example:
Examples are Trichoderma spp that control pathogens such as Rhizoctonia, Phytophthora pathogens and Armillaria. Actinomycetes control many pests and diseases. Predatory nematodes control root burrowing nematodes and organisms such as Metarhizium and Bacillus thuringiensis kill a range of insects.

3.1.2. Pest characterisation and monitoring

The most efficient method of dealing with pests and diseases is to be proactive and have a pest management plan. Generally the best results are obtained by developing a plan that uses a range of strategies taking a whole-farm approach.

Unfortunately, in most agricultural practice, pest management is an ad hoc process. It is either a belated reaction to a pest event or a very inefficient spray programme that usually kills all the beneficials, causes environmental damage and health problems.

Integrated Pest Management (IPM) has been introduced to many industries and is seen as a useful point of departure in moving towards an agro-ecological system. The IPM tools of monitoring, setting pest level thresholds and "Hot Spot"spraying are all very useful.

Effective monitoring is not exclusive to IPM and has always been regarded as an essential tool in good farming practice. There is an old Chinese saying: "The footsteps of the farmer are the best fertiliser". This saying refers to the fact that monitoring and understanding what is happening in the crop and on the farm as a whole, is one of the most important management tools as it allows the farmer to take timely actions to prevent crop damage and loss.

This means that pests and diseases should be continuously controlled by the ecological systems the majority of the time. However no system, natural or man made is infallible. Good farmers will monitor and have a back-up strategy to deal with problems when they arise.

Good organic farmers move beyond IPM by applying Eco Functional Intensification. One of the great advantages of Eco Functional Intensification is that once these systems are in place, the ecology is doing the work to control the pests and disease with the help of the farmer.

Management is the critical issue in dealing with pests and diseases

1. The first stage of a plan is to identify all the pests and diseases that cause problems for each specific crop. While this isn't always possible, as nature always tends to throw something new into the system, this process allows the farmer to effectively deal with the vast majority of the problems.

2. It is important to know how to identify pests and diseases. It is also important to be able to identify the beneficial species and those numerous species that are just part of the system but do no harm. Without this knowledge, it becomes difficult to understand what is being monitored. Constant monitoring will give good warning of known and unknown pests in most cases.

3. The next stage is to make lists of all the control agents that can be used. These can be ecological, cultural, biological and natural chemicals. It is important to find as many methods as possible and not be locked into one solution. Experience has shown that pests and diseases can become resistant to one single control method. A combination of solutions that uses different modes of action is always the most effective and will be useful in the long term.

4. Divide these strategies into short term and long term controls. Ideally in organic agriculture it is best to set up self-sustaining, ecological systems that control the pests. However there are times, especially in the beginning when converting to an organic system, when pests can get out of control. These are the times when farmers need an organic spray or the rapid use of a biological control.

5. Write down how,where and when to apply these control methods. Remember, constant monitoring to determine pest damage and levels is the key to applying the control strategies.

6. Keep good records. It is now a requirement of organic certification that a spray and inputs diary is kept. This is an extremely useful tool for analysing the effectiveness and trends in pest control methods.

7. Constantly monitor and review the plan every season. Pests and crop production are dynamic systems. Like the weather they are constantly changing. A good plan is continually improved.

3.2 Curative methods of protection

3.2.1 Biological control

Biological methods of controlling pests are excellent examples of Eco Function Intensification. A range of ecological solutions are used to replace the need for spraying to kill the pests and diseases. The ecology does the control work.

Insectaries – Beneficial insects and their host plants

Insectaries are groups of plants that attract and host beneficial insects, arthropods and higher animal species. These are the species that remove arthropod (insect) pests from farms, orchards and gardens. They are known collectively as beneficials.

Many beneficial insects have a range of host plants. Some useful species such as parasitic wasps, hoverflies and lacewings have carnivorous larvae that eat pests; however, the adult stages live mostly on nectar and pollen from flowers. Flowers provide beneficial insects with concentrated forms of food (pollen and nectar), to increase their chances of surviving, immigrating and staying in the area.

Very importantly, flowers also provide mating sites for beneficials, allowing them to increase in numbers.

Without these flowers in a farm the beneficial species move away or die and do not reproduce. Most farming systems eliminate these types of plants as weeds. Consequently, they do not have enough beneficials to exercise good pest control. Buying and releasing commercial quantities of these insects is not possible in most developing countries or is very expensive, especially if they cannot reproduce due to a lack of habitat.

Example:
Parasitic wasps prefer very small flowers. However, they have been found on large scented flowers such as water lilies. Flowers with high nectar and pollen content are regarded as the most valuable. Many weed species have these characteristics and are therefore very important in the control of insect pests.

Research into insectaries has been conducted at the University of California, Davis; the Dietrich Institute in California; Michael Field Research Station, Wisconsin; Rutgers University New Jersey; Lincoln University in New Zealand, FiBL in Switzerland and several European universities. They have shown that planting these host plant species as ground covers, in rows or in marginal areas, can result in a dramatic decline in pest species.

Farmers in the USA who have planted out rows of these host plants as "insectaries"in their fields, no longer have to spray and have similar levels of pests as their neighbours, who spray heavily with toxic chemicals.

Encouraging nectar and pollen rich flowers in and around the farm will improve the efficiency of these areas by changing the species mix in favour of these beneficials. Ongoing research is determining the most effective mixes of plant species and distances between these nature strips.

University of California, Davis researchers have shown that high levels of vegetation species diversity will ensure a constant low population of many arthropods that serve as "food"for the beneficials. The vegetation also helps to protect the beneficials, ensuring that they will stay in the area.

Taller host vegetation will contain significantly more beneficials than short vegetation. It is similar to high rise buildings being able to hold more people per sq km than single storey houses.

The research also showed that a high diversity of host plant species resulted in higher levels of beneficials and better control of pest species.

Three good rules for designing insectaries

1. Any flowering plant that attracts bees is suitable as an insectary plant. Beneficial insects prefer species that are rich in pollen and nectar

2. Smaller flowers are best for parasitic wasps

3. The greater the diversity of species, the more effective the insectary system

Research from Lincoln University in New Zealand and from The University of California, Davis has shown that it is best to weed in stages, always leaving good refuges of weeds in and around the farm to ensure a healthy supply of beneficial species. Never control all the weeds on the farm at the same time.

Dust interferes with predatory insects' ability to locate hosts and can lead to outbreaks of pests like spider mites. Planting insectary plants as windbreaks and ground covers will reduce dust.

Beneficial 'Insect hotels'

A collection of suitable artificial materials that can serve as a breeding habitat for beneficial insects is also sometimes called an insectary. Such materials include clay bricks, wooden logs with holes in various size drilled into them, and reeds or bamboo in different diameters bundled together. They serve as safe spots for the beneficials to lay their eggs and be nurseries for their offspring.

These 'bug/insect hotels' are often all creatively combined in one location with a suitable protective roof and can be an artistic feature in a garden or on a farm.

Trap crops

Trap crops are a variation of insectaries and are used to trap pest species. There are a range of methods and types of crops that are used.

1. Continuous preferred hosts

These work by drawing the pest species away from the crop because they prefer the trap crop to the cash crop.

Example:

American cotton farmers plant rows of lucerne (Alfalfa) in their fields because lygus bugs prefer lucerne over cotton. Farmers alternately mow half the row for the full length every two weeks. This creates a continual strip of lucerne that is in the correct state for the lygus bugs as well as leaving most of the beneficials in the lucerne.

2. Timed alternate hosts

These work by planting crops that attract the pest species before or after the season. The pests are then destroyed to break the breeding cycles and reduce the pest population.

Example:

Some crops attract nematodes. These crops are usually planted early in the season and ploughed in as a green manure before the nematodes begin laying eggs. Used properly, this system will break the pest cycle, reduce weeds and provide valuable organic matter and slow release nutrients for the cash crop.

A variation is to plant the trap crop straight after the cash crop. Usually the pest species is at its greatest at this point. A combination of a trap crop and a rotation cash crop the following year have been shown to be the most effective in significantly controlling pests.

Another version of this method is to plant a few small areas of the cash crop a few weeks earlier and plough it in just before planting the main cash crop. Timed properly, this can significantly reduce pests.

Example:

An example of this is the use of Jaboticaba trees that flower just before lychee or mango trees. The Jaboticaba flowers will attract the monolepta beetles where they can be destroyed before they attack the lychee and mango flowers.

The use of alternate hosts that attract the pest early in the season can be useful.

Example:

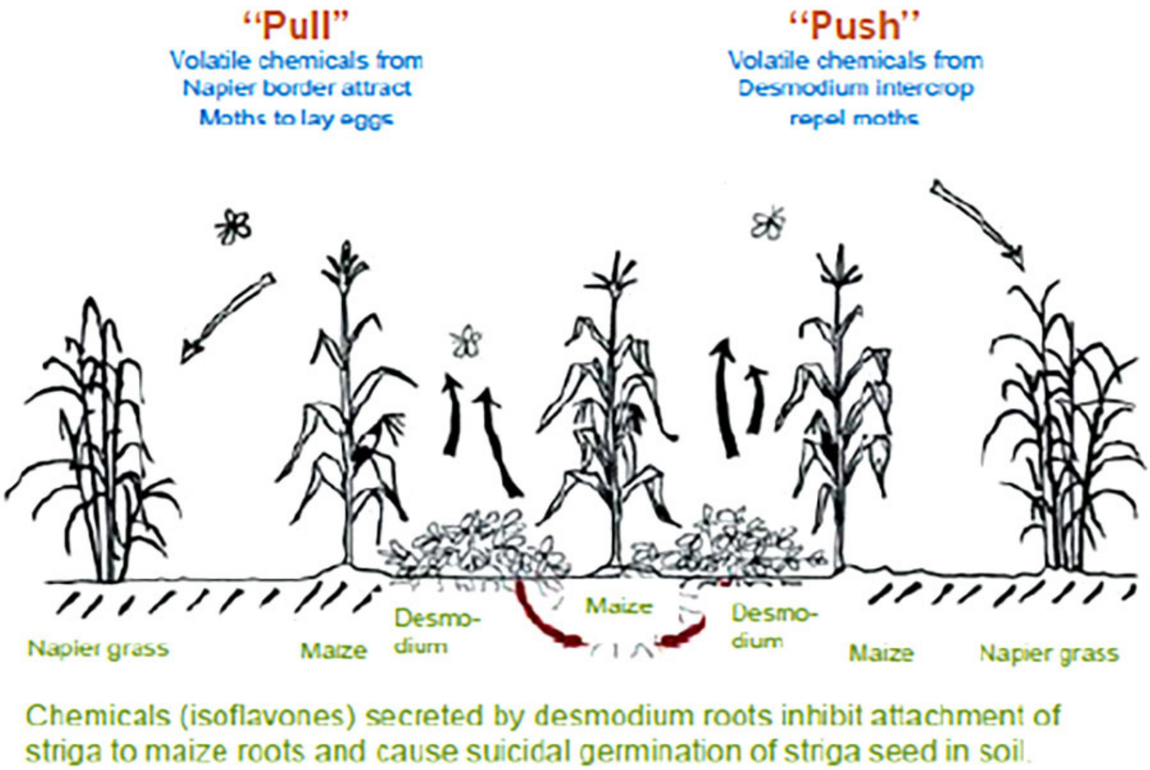
Chickpeas (Cicerarietinum) make the best trap crop for the pesticide resistant heliothis (Helicoverpa armigera). Linseed (Linum usitatissimum), canola (Brassica napus) and field peas (Pisumspp)were shown to be good trap crops for heliothis and host plants for predators and parisitoids such as lacewings, ladybirds and wasps.

3. Lures

Insectaries can be used as trap crops by placing/spraying lures and baits to attract the pest species out of the cash crop and into the predator rich insectary.

- **Repellent species**

Some plants repel insect pests. Interplanting repellent species within the crop will make it less attractive to the pest. Having a non-crop plant that is a preferred host planted near the crop will attract the pest away from the crop.



- **Push-Pull method**

The best systems work by integrating several of the bio-control strategies into a "whole-systems approach".

The Push–Pull method in maize is an excellent example of an organic method that integrates several of these elements to achieve substantial increases in yields. This is significant because maize is the key food staple in Africa and Latin America. The Push-Pull system was developed by scientists in Kenya at the International Centre of Insect Physiology and Ecology (ICIPE), Rothamsted Research, UK and in collaboration with other partners.

The Push-Pull method is an excellent example of Eco Function Intensification as an integrated production system. It uses the combination of a cover crop and a trap crop to prevent stem borers and the striga parasite in maize.

Desmodium is planted to repel the stem borer and also to attract the natural enemies of the pest. Its root exudates stop the growth of striga, which is a parasitic weed of maize. Napier grass is planted outside of the field as a trap crop for the stem borer. The *desmodium* repels (Push) the pests from the maize and the Napier grass attracts (Pull) the stem borers out of the field to lay their eggs in it instead of in the maize. The sharp silica hairs on the Napier grass kill the stem borer larvae when they hatch to break their life cycle and reduce pest numbers. Sometimes fodder sorghum is used instead of the Napier grass.

High yields are not the only benefits. The system does not need synthetic nitrogen as *desmodium* is a legume that fixes nitrogen. Soil erosion is prevented due to permanent ground cover. More significantly, the system provides quality fodder for livestock.

The buffer strip of Napier grass is systematically strip-harvested to provide fresh fodder for livestock. Livestock can also graze down the field after the maize is harvested.

Many Push-Pull farmers will integrate a dairy cow into the system and sell surplus milk as a regular source of income.

- **Barriers**

Trap crops and permanent insectaries can be used as a barrier to prevent the entry of pests into a cash crop.

Farmers in Myanmar plant barriers of sunflowers around their fields. The sunflowers act as barriers to stop pests from entering the field as they get attacked by the beneficials in the sunflower barriers. The beneficials can also enter the field to protect the crop.

Traditionally, many farmers, have hedge borders of different plants growing along the pathways and farm boundaries with a diverse collection of native and introduced species. This is very common in some parts of Africa. These border hedges act as refuges for beneficials, as well as barriers for pests.

- **Higher animals**

Insectaries – or nature strips – are also hosts to valuable higher animals. A large range of higher species play significant roles in controlling pests in agriculture.

Many bird species will eat pest insects. Examinations of the crop and stomach contents of most bird species commonly found on farms show that they can consume large numbers of insects. Each bird can eat thousands of insects per year.

Other published research has shown that one of the major problems with widespread herbicide use is the loss of the habitat refuges of birds and beneficial insects. The bird numbers plummet in these districts, resulting in higher pesticide use.

Studies of orchards using total exclusion netting have demonstrated that these orchards need to use more insecticides to kill pests that were previously eaten by birds.

Dense bushes, small trees, shrubs and bamboos should be used to attract insect eating birds. Most of these are small birds, which like to shelter and nest under thick canopies to avoid predators.

Micro-bats are very effective in controlling many night flying insect pests. Each bat can eat one third of its body weight in insects every night. This is a massive number of insects and farmers build bat houses to keep them on the farm. They also place lights in the crop to attract insects for the bats to eat. Many farmers also collect the bat guano around the bat houses as fertiliser.

Micro-bats can be used to control fruit sucking and piercing moths by putting a battery-powered light in the sections of the orchards where pest control is needed. The bats are attracted to the light, as they know that light attracts many insects. They can also locate and eat nearby moths using their sonar.

Lizards, frogs and toads eat a wide range of pest insect species. Piles of rocks provide shelter during the inactive time for those predators. A light placed on the ground at night will attract frogs and toads to consume the insects that are drawn by the lights. Many pest beetle and moth species can be controlled this way.

Poultry – chickens, ducks, peafowl and guinea fowl are very effective in cleaning up pest species like grasshoppers and beetles. These animals have been used traditionally in all farming cultures as an essential part of pest control.

Owls are proving effective in controlling rats and other rodents. Owl nesting boxes are placed in high trees to encourage these hunters to live and breed close by. It is important to have perch trees and a cleared border, at least 2 metres wide around the field, so that the owls can see and catch rats as they run in and out of the fields. Other birds of prey are also attracted by tall perch trees. Alternatively, tall T-poles can be erected around fields or orchards to provide perching possibilities for the raptors.

- **Planting non pest host species and pest resistant varieties**

Where possible, it is important to source crop varieties that are resistant to major pests and diseases.

Many weed or garden plants can host insect pests. As an example, some pest beetle species such as cane beetle, Monolepta and Rhyparida larvae live on the roots of grasses.

Many pest rat species nest and live in long grasses. Replacing these with shrubs and trees and other flowering plants will reduce their numbers.

Eliminating or reducing these pest host species (except when used as trap crops) with beneficial plant species will significantly reduce the damage the pests cause in the crop.

- **Purchasing beneficial arthropods**

Many beneficial insects can now be purchased in certain countries. The following groups of arthropods are usually available:

- Predatory nematodes
- Predatory mites
- *Trichogramma* and other parasitic wasps
- Lacewings *(Chrysoperlaspp.)*
- Ladybirds *(Coccinellaspp.)*
- Assassin bugs and other predatory bugs

- **Baits, lures, traps and pheromone disrupters**

A range of traps, baits and lures are used to control insects. These are some of the best methods as they concentrate on controlling pest species without adversely effecting non target species.

Examples of these are protein hydrolysate baits for fruit flies. These tend to mostly attract the females; however they will also attract many males. The flies feed on entero-bacteria that live in the protein bait. The bait should be contained in a vessel that prevents escape and/or has enough water to drown the insects.

Pheromones and/or para-hormones can be used as baits or as methods to disrupt mating. Variations of these are now being used very effectively with codling moths and fruit flies and are available commercially.

Borax and sugar baits can be used to control a large range of insect pests, particularly cockroaches and ants. Use soil tests to ensure that the levels of boron are not too high as it can be toxic to plants. If the tests show boron deficiencies, then it can be used without causing any soil problems.

Sticky pastes can be applied around the trunks of trees to trap insects such as ants that climb up the trunk. Coloured sticky traps can be used; however they tend to be better as a method of monitoring the pest numbers rather than as a significant control method.

3.2.2. Physical control

Allowable organic sprays and spray technology

Spraying (organic) pesticides and fungicides should be regarded as the tools of last resort in organic systems. Ideally a good organic farmer tries to avoid pests by having healthy fertile soil and good biodiversity on the farm. However there are certain pests that can periodically cause economic damage if they are not controlled at critical times.

Constant monitoring and timely action can control these before they increase into a significant problem. As stated in section 3.1., it is important to be able to identify the pests and also the threshold levels at which they cause economic damage.

Just finding a few pests does not necessarily mean that there will be any economic damage to the crop. In fact small levels of the pest are good in balanced ecological systems as these will provide constant food sources for the predator (beneficial) species that feed on the pest. Wiping out all the pests with a widespread spray programme means that the beneficial species will starve and also be wiped out.

This means that when the pests arrive back in the crop, they will have no natural bio-controls and quickly multiply to cause economic damage. This tends to lock farmers into never ending, and at times, escalating spray programmes.

This needs to be avoided by developing Eco Function Intensification systems that attract the beneficials that will control the pests. The critical issue is to understand the threshold levels of the pest that will cause economic damage. It is at this point where a spray may be necessary.

Monitoring and only spraying hot spots

Many organic sprays are broad spectrum, killing both pest and beneficial species. The best approach is to avoid complete cover sprays of the crop, unless using a spray that only targets a specific pest such as *Bacillus thuringiensis*.

When using a broad spectrum spray (such as natural pyrethrum, potassium soaps, diatomaceous earth, clay, flour and water or vegetable oils), monitor the crop and establish the areas that have the highest numbers of the pest. These areas are the "Hot Spots".

Only spray the hot spots. This allows the beneficial species to survive in the rest of the crop and they will help to give good control.

Killing all the beneficial species can lead to an increase in the pests and allow new pests to manifest. It could also lock organic farmers into the same spray dependency as conventional farmers.

One of the important differences between allowable organic insecticides and most synthetic pesticides is that most organic formulations biodegrade within 24 hours or become plant nutrients.

This is good for the environment and for consumers; however the lack of persistence means that they need to be applied more often. Monitoring is crucial in determining the best time and places to spray.

Avoid calendar spraying such as weekly or fortnightly. This can result in spraying when there are no pests and not spraying when there are pests. Always monitor and check pest levels before deciding on the appropriate control strategy.

A valuable control method is to monitor pest numbers following a spray application and then using another spray two days later. This will give excellent pest control as it tends to catch the pests that were hiding under leaves during the first application and have moved to new areas where they can be exposed to the spray droplets of the second application.

The only time it is useful to apply pesticides and fungicides on a regular cyclical basis, is when this is based on known life cycles. This timing is usually based on the period after eggs hatch to before they are mature enough to reproduce. Spraying three of these life cycles is usually sufficient to significantly disrupt the breeding cycle of most pests and diseases.

Biological sprays

Non-toxic sprays

Biological pesticides such as Bacillus thuringiensis and Metarhizium are usually pest specific and do not harm beneficials or people. These can be used as complete cover sprays over the whole crop to gain effective control. Many people do not succeed with biological sprays, because they do not realise that they are dealing with living organisms rather than a chemical. Biological sprays need to live in suitable conditions to be effective. It is important to understand these requirements or they will die soon after application and become useless.

This is one of the fundamental reasons why the results of biological products can be unreliable. They can work exceptionally well in some trials and have no effect in others.

Example:

Bacillus thuringiensis var. Kurstaki (BT) is very effective in the control of lepidoptera (caterpillars).

It is most effective when the caterpillars are in the early stages of growth. It works only when the caterpillar ingests the living bacteria. These bacteria make sharp protein crystals called lectins that literally cut up the digestive system of the pest. The pests immediately stop feeding and die over a few days.

BT cannot survive in ultra violet light. Spraying it in the morning or middle of the day will kill it before it has a chance to work in warm temperate and tropical climates. It is important to spray in the late afternoon or early evening so that it has all night to work. It will die in the sunlight of the following day. The product is sold as a dormant spore. It is best to culture this for several hours to break the dormancy and get the spores to grow and multiply as active bacteria. This increases the chances of caterpillars eating the Bt.

Just mixing the spore powder with water and spraying it without allowing it to develop, will mean that it will take several hours after spraying before any bacteria will become active. By the time the numbers of bacteria are multiplying they will be killed by the morning sun.

The most effective method is to mix the spore powder in milk or in a diluted water and molasses mix and leave in a shaded area for a few hours.

The cultured mix is later added to a bonding agent such as an emulsified vegetable oil. The oil will ensure that the droplets stick to the leaves of the plants when sprayed.

Effective rates: 100gms of Bt mixed with 500mls of molasses and 2 litres of water for 2 to 3 hours. 500mls of emulsified vegetable oil (Spray-tech Oil, Synetrol Oil, Eco Oil) is then blended into this. This will make 100 litres of spray. Keep the tank regularly agitated or shaken to prevent the spores from settling to the bottom.

Emulsified vegetable oils are very effective at killing all arthropods (insects and related species). These work by clogging their breathing pores so that they suffocate. It is important to ensure complete coverage of the pest species.

Natural soap sprays such as potassium soaps kill insects by dissolving the outer cuticle and also by clogging their breathing pores.

The research on Kaolin as an effective means of controlling pest and some diseases continues. Diatomaceous earth. This works by both clogging up the pores and the sharp silica edges shred the joints of the pests.

These types of sprays are non-specific and will kill beneficials so they should only be used on "hot spots". The oils and soaps can also burn leaves if used in high concentrations, so it is important to test sprays first.

Toxic sprays

Natural pyrethrum is very effective for every pest because no insect has developed resistance to it. This is because it is a natural extraction of a mixture of different pyrethrums, with every batch having different combinations. This means if an insect pest begins to develop resistance against one batch, the following year's batch of natural pyrethrum will be different enough to ensure that the pests have no resistance to it.

Pyrethrum is a nerve poison and has caused blindness in people who have been exposed to it. It is highly toxic to all cold blooded animals, especially fish, so it must be used with care. It breaks down completely in four hours in warm blooded animals and in 24 hours in the natural environment leaving no toxic residues.

Rotenone – Derris dust is a highly toxic and effective nerve poison for all species especially cold blooded animals. Like natural pyrethrum, it breaks down completely in a few hours in warm blooded animals and in 24 hours in the natural environment.

Eucalyptus oil is highly toxic. As little as a teaspoon can kill a child. Used correctly it makes a very effective insecticide.

All of these insecticides work by direct contact with the insects. Mixing them with soaps ensures they work more effectively as the soap dissolves the outer cuticle of insects, allowing the toxin to penetrate more effectively.

When the soap and toxin mixture is combined with the vegetable oil bonding agent, they are even more effective. The oils ensure that the spray droplets stick to the pest. The oils smother the pests and the soap damages the cuticle, giving three modes of action.

Never use these types of sprays as cover spray, as they are highly toxic and also disruptive to beneficial predators. They should be restricted only to "Hot Spot"spraying.

Repellents

Several compounds have been shown to work effectively by repelling rather than killing the pests. These have major advantages as they protect the crop without killing the beneficials.

Example:

Examples of these are garlic, chilli, tea tree oil, lavender oil, citronella oil (this oil can also attract some species like fruit flies due to the eugenol content) and cypress pine oil.

3.2.3 Mechanical control

Crop rotations

Crop rotations are regarded as one of the most effective ways of controlling pest and disease cycles. Many pests and diseases are crop specific. By harvesting and removing all residue from the previous crop and planting a very different crop in its place, the pest or disease dies due to a lack of suitable hosts.

It is one of the oldest and most consistently proven methods. F.H. King gives numerous examples of how it has been used for thousands of years in sustainable systems in China, Japan and Korea in his book *'Farmers of Forty Centuries – Permanent Agriculture in Japan, China and Korea'*. Even though this book was published in 1911, the numerous examples of rotation systems, especially for horticultural production of fruits, vegetables and beans are still valid today. Many of these systems are still being used in the remote rural areas of China as effective ways to reduce pests and diseases.

Another variation of crop rotation systems is the planting of trap crops. These were discussed above. Rotation crops can also be used as Insectaries. Winter cereals such as wheat, oats and sorghum have been used as beneficial nursery crops for the following crop.

There are some instances where breaking the cycle can also severely reduce beneficial micro-organisms like *Metarhizium* that controls cane beetles and phosphorous producing VAM fungi in wheat. There is evidence that the best way to overcome this problem is to inoculate the new crop with the spores of the beneficial species. Adding good locally made compost can be another way to stimulate the growth of the beneficial micro-organisms.

Strategic tilling

This is where tillage is timed in combination with some biological methods. Tillage is used in conjunction with trap crops and is timed so that the host crop is destroyed before the pest can reproduce. They are particularly used for soil pests and disease such as nematodes/eel worms. The key is to allow the pest the time to lay their eggs and have them hatch and destroy the food source at this point. It will decimate a whole generation of these pests and significantly lower the pest levels.

This should be followed with a crop rotation of species that are not hosts to these pests. This will further disrupt their reproduction cycles and reduce the pest levels down to the point where there should be no economic thresholds of crop loss.

Pruning

Pruning crops to allow air movement and sunlight penetration is one of the most effective ways to control fungal disease. Most fungal diseases like damp, shady conditions. The ultra violet light in sunlight is fatal to many plant diseases and air movement can dry out many surface dwelling disease organisms.

The correct pruning methods are also very important if a crop needs to be sprayed for pests or diseases. This will allow the spray to penetrate and surround the whole plant and make contact with the pest or disease. The normal structure of many plants means that a dense canopy of leaves will prevent the spray from entering the inside of the canopy, allowing the pest or disease to escape from contact with the spray.

However, it is important to understand the right shape of any tree crop and if it needs to be pruned to allow sunlight and air movement to control pests and diseases, do it judiciously. In most cases this might not be necessary and can even be detrimental to high yields. Plants need their leaves for photosynthesis. The more leaves, the more photosynthesis.

A dense canopy is better for small birds so that they can hide from their larger bird predators. They will feel safe inside the canopy and spend hours searching for the pests as their food sources. This is also the same for many beneficial insects.

The need for pruning has to be a considered management decision, based on the specific crop and its major pests and diseases.

3.2.4 List of organic insecticides, fungicides and biological controls

Below are lists of many of the natural compounds and biological controls that are allowed to be used in certified agriculture. This is by no means a complete list and there are many other natural compounds and biological controls that are available. It is always worth doing more research.

Good farmers will always use a diverse range of these as part of their pest and disease management systems. Certified organic farmers must check with their certifiers before using any of these as some certifiers may have restrictions on some of the compounds on the lists below.

Botanical and simple natural chemicals

- Natural pyrethrum
- Rotenone
- Quassia
- Ryania
- Propolis
- Emulsified vegetable oils
- Mineral oils
- Essential oils – tea tree *(Melaleuca alternifolia)*, eucalyptus, citronella *(Cymbopogoncitratus)*, lavender *(Lavandula spp.)*, cypress pine *(Cupressus spp.)* etc.
- Potassium soap
- Plain soap
- Sodium silicate (waterglass)
- Neem *(Azadirachtaindica)*
- Copper sulphate
- Lime
- Sulphur
- Potassium permanganate
- Borax
- Baking soda
- Diatomaceous earth
- Stone meal
- Sea salts
- Kaolin
- Flour and water
- Chilli sprays
- Garlic
- Vinegar and wood vinegar
- Tobacco (usually as tobacco teas –not pure nicotine)
- Bluish dogbane
- Pheromones
- Bordeaux mixture
- Burgundy mixture
- Copper sulphate, Copper carbonate
- Sodium bicarbonate
- Vinegar and wood vinegar
- Yogurt and other natural lactic acid fermented milk products
- Milk, whey and milk solids
- Synthetic chemical lures and baits are allowed if they are enclosed so that they do not leach into the environment.

Biological controls

Bio-pesticides

Various bacteria, fungi, viruses and their naturally produced metabolites are allowed. Please note that many of these are very susceptible to insecticides, fungicides and particularly many herbicides.

- *Bacillus thuringiensis – var.kurstaki* for caterpillars
- *Bacillus thuringiensis – var.enebrionis* for beetles
- *Bacillus thuringiensis – var.israeliensis* form mosquitoes and some flies
- *Metarhizium* species for grasshoppers, beetles, white flies and a range of insects
- *Trichoderma* species for controlling diseases
- *Cliocladiun virens* for controlling diseases
- *Bacillus subtillus* for controlling diseases
- *Verticilium lecanii* for scale insects, aphids and white flies
- *Beauveria basiana* for a wide range of insects

Fresh, good quality compost will have high levels of actinomycetes, protozoa and beneficial fungi that will control a wide range of pests and diseases.

Beneficial insects and arthropods

Many beneficial insects can now be purchased. The most effective way to introduce these creatures onto the farm is to provide insectaries. Insectaries provide the equivalent of many thousands of dollars' worth of beneficial species weekly – at no cost.

- *Trichogramma, telenomus* and other parasitic wasps
- Predatory nematodes
- Predatory mites
- Hover flies
- Assassin bugs
- Praying mantis
- Lacewings
- Lady beetles
- Spiders
- Dragon flies

Insectary plants

Any flowering plant that attracts bees is suitable as an insectary plant. Insects prefer species that are rich in pollen and nectar. Smaller flowers are best for parasitic wasps.

Most flowering weeds are valuable insectary plants. Also, many native flowering plants should be suitable.

Temperate species

- Willow sp. *(Salix spp.)*
- Clovers *(Trifoliumspp.)*
- Vetch *(Vicia spp.)*
- Coriander *(Coriandrum sativum)*
- Buckwheat *(Fagopyrumesculentum)*
- Lobelia *(Lobeliaspp.)*
- Yarrow *(Achilleamillefolium)*
- Elderberry *(Sambucusspp.)*
- Alysium *(Alyssumspp.)*
- Water lilies *(Nymphea)*
- Dill *(Anethum graveolens)*
- Coriander *(Coriandrum sativa)*
- Fennel *(Foeniculum vulgare)*
- Marigolds
- Canola
- Wheat
- Sorghum
- Lucerne
- Linseed
- Field peas
- Tansy leaf
- Maize

Tropical species

- Sensitive weed *(Mimosa pudica)*
- Crotalaria *(Crotalariasp.)*
- Pigeon peas *(Cajanuscajan)*
- Pinto peanut
- Marigolds
- Sorghum
- Stylosanthes sp.
- Water lilies
- Maize

Fungicides

- Sodium bicarbonate powder
- Copper compounds (copper hydroxide and copper oxychloride)
- Effective Microorganisms (EM)
- Indigenous Microorganisms (IM)
- *Trichoderma spp (beneficial soil fungus)*
- *Bacillus subtilis*

3.3 Pest and disease management plans for typical pests and diseases in Namibia

Preventive (long term) measures

Cultural practices
Crop rotation, enhancement of soil quality, choice of resistant varieties, water management, monitoring/screening, field sanitation, mechanical barriers, post-harvest treatment

Habitat management
Wild flower strips, hedgerows, functional biodiversity (regulation of pests through conservation and enhancing of indigenous natural enemies)

Biological pest control
Introduction of predators and pathogens (e.g. beneficial insects, bacteria, viruses, fungi)

Bio-pesticides and physical measures
Plant extracts, natural products, pheromones, insect traps and baits

(Synthetic pesticides)

Curative (short term) measures

3.3.1. Fungal diseases

3.3.1.1. Anthractnose

3.3.1.1.1. Scientific and common names

Colletotrichum spp./Gloeosporium spp./ Glomerella spp. / Sphaceloma (Elsinoe) spp.
Anthracnose, brown blight (of coffee and tea), tear stain, dieback (citrus), fruit rot, stem canker, black spot of fruit, ripe rot of pepper, anthracnose tear-stain (mango)

3.3.1.1.2. What it is

Anthracnoses are diseases of the foliage, stems, or fruits that typically appear as dark-coloured spots or sunken lesions with a slightly raised rim. Some cause twig or branch dieback. In fruit infections, anthracnose often has a prolonged latent stage. In some fruit crops, the spots are raised and have corky surfaces. Anthracnose diseases of fruit often result in fruit drop and fruit rot. Anthracnoses are caused by fungi that produce conidia within black fungal fruiting bodies called acervuli. *Colletotrichum* species are responsible for most anthracnose diseases. They are found in nature mostly in their conidial stage (asexual) and can over-season as mycelium (fungal threads) or conidia (spores) in foliage, stems, twigs and infected crop debris.

Colletotrichum diseases are the most common anthracnoses and are very similar, if not identical, to the diseases caused by *Glomerella*. The latter is probably the sexual stage of most or all species of *Colletotrichum (Gloeosporium)*. Anthracnose diseases, particularly those caused by *Colletotrichum (Gloeosporium)* or *Glomerella* fungi are very common and destructive on numerous crops and ornamental plants. Although severe everywhere, anthracnose diseases cause their most significant losses in the tropics and subtropics. The diseases thrive in wet, humid, warm conditions and are spread by infected seed, rain splash and moist wind.

The lifecycle of anthracnose diseases essentially involves the production of spores on susceptible hosts, dispersal of spores, penetration of host tissue, initiation of an infection process within the cells, development of lesions, formation of bristly spores and dispersal usually by water-splash, air currents, insects or other forms of contact.

The *anthracnose* pathogen reaches its most serious dimension at high moisture levels and warm temperatures. For example *C. gloeosporioides* has an optimum of 25°C to 29°C but it will also survive at temperatures as low as 4°C. Spore germination, dispersal and infection require relative humidities near 100%. However, in drier conditions, disease expression can occur when latent infections are activated through aging or tissue damage.

The anthracnose diseases are primarily transmitted through seed, but also through infected plant parts. Rain splash will also disperse spores within the crop canopy. The pathogen persists on and in seed, crop residues and weed hosts.

Major species of anthracnose fungi affecting crops in Africa:

- Anthracnose of avocado *(Glomerella cingulata)*
- Anthracnose of cotton *(C. gossypii)*
- Anthracnose of cucurbits *(C. lagenarium)*
- Anthracnose of grapes Sphaceloma (Elsinoe) ampelina
- Anthracnose of lime *(Gloeosporium limitticola)*
- Anthracnose of spinach *(C. spinacicola)*
- Anthracnose of tomato *(C. coccodes, C. phomoides)*
- Banana anthracnose *(C. musae)*
- Bean anthracnose *(C. lindemuthianum (Glomeralla cingulata)*
- Cereal anthracnose *(C. graminicola)*
- Common scab of citrus Sphaceloma *(Elsinoe) fawcettii)*

- Coffee anthracnose *(C. coffeanum)*
- Mango anthracnose *(C. gloeosporioides)*
- Onion smudge *(C. circinans)*
- Pea anthracnose *(C. pisi)*
- Pepper anthracnose *(C. capsici)*
- Red rot of sugarcane Glomerella tucumanensis *(C. falcatum)*
- Watermelon anthracnose *(C. lagenarium)*

3.3.1.1.3. The damage caused

Flower infection on mangoes (blossom blight) can destroy flowers and young fruit and cause complete crop failure. Fruit infection may cause premature fruit drop, but major fruit losses occur during ripening when quiescent (dormant) infections break out and cause the spread of black lesions. Anthracnose of other fruits also causes major post-harvest losses. Heavy infections cause rapid rotting and even light infections which cause mainly cosmetic damage, will shorten fruit storage life. Because of the variability between seasons and locations, overall figures for losses are difficult to assess, but it is clear that in many mango-growing areas, losses of up to 50% of the crop due to the various stages of the disease would not be uncommon.

Of the foliage diseases caused by *C. gloeosporioides*, yam anthracnose can be one of the most economically damaging and may prevent significant growth of tubers if the disease strikes early.

Anthracnose infected vegetables (e.g. beans, brinjals, peas, pepper and cucurbits) and fruits (e.g. avocado, mangoes and bananas) are not suitable for the export market.

Symptoms

Anthracnose diseases attack all parts of the plant at any growth stage. The symptoms are most visible on leaves and ripe fruits. At first, anthracnose generally appears on leaves as small and irregular yellow, brown, dark-brown or black spots. The spots can expand and merge to cover a large area. The colour of the infected part darkens as it ages. The disease can also produce cankers on stems. Infected fruit has small, water-soaked, sunken, circular spots that may increase to a size of up to 1cm in diameter. As it ages, the centre of an older spot becomes blackish and emits gelatinous pink spore masses.

Anthracnose Avo

Anthracnose on dry beans

Anthracnose on sorghum

Anthracnose on pumpkin

Affected plant stages
Flowering stage, fruiting stage, post-harvest, seedling stage and vegetative growing stage.

Affected plant parts
Leaves, stems, fruits/pods and inflorescence.

3.3.1.1.4. Cultural practices to prevent its occurrence

Field sanitation

1. Field sanitation is an important and highly effective farm practice to keep most diseases under control
2. Use certified disease-free seeds. Anthracnose is seed-borne
3. Make a proper selection of healthy plants for transplanting
4. Keep weeds under control at all times. Keep the surroundings of your farm free of weeds, unless they are maintained and intended as habitat for natural enemies
5. Make yourself 'clean'. Always bear in mind that you might be the carrier of the diseases while you move from one plant to another
6. Pull out plants that are heavily infected
7. Prune the plant parts of fruit trees that show severe symptoms of disease infection
8. Properly dispose of all the infected plants
9. Pick rotten fruits and collect those that have dropped and bury them in a pit
10. Plough under crop residues and organic mulches. This improves soil condition and helps to disrupt the disease lifecycle
11. Maintain cleanliness on the irrigation canals
12. If possible, remove all the crop residues after harvest. Add these to your compost pile
13. Make your own compost. Your compost pile is where you can place your plant trimmings and other plant debris
14. Clean your farm tools. Wash ploughs, harrows, shovels, trowels and pruning shears after use. Lightly oil pruning shears

Hot water seed treatment
When using your own seed, treat it with hot water *(see 5. Common control methods for pests & diseases)*

Pruning
Pruning is the selective removal of specific plant parts, such as shoots and branches. It is particularly important for fruit trees. Pruning done on a regular basis as part of plant care achieves the following:

- It makes the plant less dense
- It improves the air circulation and sunlight penetration. Together these conditions decrease the incidence of diseases and limit the conditions that promote fungal growth. It also allows better spray penetration and coverage
- It improves the appearance and health of plants
- It rids the infected parts of disease
- It allows natural enemies to find their prey easily
- It controls the size of a plant
- It trains young plants
- It encourages early vegetative growth

Reminders for crops that need pruning in their management

- Pruning is best done during dry weather as it minimises the spread of the pathogens that cause diseases

- Always use sharp pruning tools to achieve clean and smooth cuts angled to shed water and avoid direct sunlight
- Clean your pruning tools with a 10% bleach solution and wash your hands and pruning tools between pruning diseased plants
- After pruning, disinfect your pruning tools with a 10% bleach solution
- Ask for assistance from your local agriculturist for the proper pruning techniques on fruit trees

3.3.1.1.5. Remedies

Copper

There are many copper compounds that are used as fungicides. The most common are derived from copper hydroxide and copper oxychloride. These products are cheap and are readily available in most African countries. They are sold under different trade names. *It is accepted in organic farming provided that the number of applications is strictly followed and a proper soil amendment is observed to prevent copper accumulation.*

In organic culture, it is advised to consult your organic certification body. Because copper products constitute propriety products, *users are advised to comply with product label instructions on dosage, frequency of application, pre-harvest intervals and product safety (proper handling, storage and disposal).*

When handling and/or applying pesticides, observe the following:

- Read and follow the label instructions carefully
- Ask for assistance from your local agriculture office when using copper for the first time
- Monitor plants regularly and spray only when necessary as copper can accumulate in the soil
- Do not smoke when handling/spraying
- Do not eat food when handling/spraying
- Spray in the early morning or late afternoon
- Wear protective clothing when handling and/or applying any pesticide (including copper)
- Wash your hands after handling pesticides

Effective Microorganisms (EM), Indigenous Microorganisms (IM)

Fungal diseases are successfully treated with the application of beneficial microbes, such as EM and IM.

For more information see 5. Common control methods for pests & diseases

3.3.1.2. Fusarium

3.3.1.2.1. Scientific and common names

Fusarium wilt

Fusarium oxysporum

Important Fusarium species:

- Banana wilt (Panama disease) *(F. oxysporum f.sp. cubense)*
- Cabbage yellows *(F. oxysporum f.sp. conglutinans)*
- Fusarium wilt of common beans *(F. oxysporum f.sp. phaseoli)*
- Fusarium wilt of cotton and okra *(F. oxysporum f.sp. vasinfectum)*
- Fusarium wilt of peas *(F. oxysporum f.sp. pisi)*
- Fusarium wilt of pigeon pea *(F. odum)*
- Fusarium wilt of tomato *(F. oxysporum f.sp. lycopersici)*

3.3.1.2.2. What it is

The fungus is both seed-borne and soil-borne. It may become established in many types of soil, but it is likely to cause most damage on light, sandy soils. It is most active at temperatures between 25°C and 32°C. Since the fungus produces resting spores (chlamydospores), it can survive in the soil indefinitely, even when no host plants are grown. It can also survive in the fibrous roots of weeds such as *Amaranthus, Digitaria and Malva*. It can spread through the movement of infested soil or infected transplants. Acidic soils (pH 5.0 to 5.6) and ammonium nitrogen (ammonium nitrate and urea) promote disease development. Infestation by root-knot nematodes enhances the disease.

Conditions that favour development

- High soil temperatures
- High nitrogen levels in the soil
- Soil moisture stress
- Fusarium infested soil

3.3.1.2.3. The damage caused

Symptoms on banana

An infected plant is characterised by a strong yellowing of the leaves that remain erect for 1 to 2 weeks. Some of the leaves may then collapse at the leaf stalk and hang down at the pseudostem. The leaves fall in order, from the oldest to the youngest, until they hang about the plant like a skirt and dry up.

The fungus grows in the vascular system causing the plant to wilt. A lengthwise cut on the pseudostem will show numerous brown and black lines running in all directions. Infected suckers growing out of diseased corms (rhizomes) produce plants that wilt and eventually die. Leaf symptoms appear after the fungus has spread through the corm (rhizome). In younger plants, the first signs of infection are to be found on the unfurling leaf which turns yellow and dies off.

Symptoms on cotton and okra (F. oxysporum f.sp. vasinfectum)

The affected plants are stunted. The leaves turn yellow, wilt and are later shed. Usually the lower leaves are the first affected. When a stem or the main root is cut crosswise, brown discolouration is usually found in the ring just beneath the bark. Wilting of plants is mostly gradual.

Symptoms on tomato

The lower leaves of the plant usually turn yellow and die. One or more branches may show definite symptoms. Leaflets on one side of a petiole may be affected, while those on another side remain without symptoms. Diseased leaves readily break away from the stem. Sometimes the affected leaves may dry up before wilting is detected.

When affected stems and petioles are cut diagonally, just above the ground level, a brown discolouration of the water conducting tissue inside the stem will be seen.

Symptoms on beans

Infection often occurs on medium-aged or older plants. It begins as a yellowing and wilting of the lower leaves. The infection progresses up the plant until the entire plant turns yellow. Plants become stunted when infected at a younger age.

To be sure that the plant is infected by *Fusarium* wilt, make a lengthwise cut on the stem at the soil line, near the base. The cut will have a dark-brownish vascular tissue below the bark. If an infected plant is uprooted, the roots are partially or totally reddish-brown in colour.

Fusarium on banana pseudostem

Fusarium on beans

Fusarium on chillies

Affected plant stages

Cotton and Okra: Seedling stage and vegetative growing stage.
Banana: Flowering stage, fruiting stage and vegetative growing stage.
Tomato: Flowering stage, fruiting stage and seedling stage.
Beans: Vegetative growing stage.

Affected plant parts

Cotton and Okra: Leaves, whole plant and roots
Banana: Growing points, leaves, roots and stems
Tomato: Leaves, stems, whole plant and roots
Beans: Leaves and roots

Symptoms on affected plant part

Cotton and Okra: Leaves: yellowing lesions; abnormal colours. Whole plant: dwarfing
Banana: Growing points: dead heart. Leaves: lesions; yellowing; wilting; Roots: rot. Stems: internal discolouration; stem splitting
Tomato: Leaves yellowing. Stems: internal discolouration. Whole plant: wilt
Beans: Leaves: yellowing; wilting

3.3.1.2.4. Cultural practices to prevent its occurrence

Spraying with fungicide will not control this disease

- Because *Fusarium* persist in soil for several years, a long crop rotation (4 to 6 years) is necessary
- Avoid using any solanaceous crop (potato, tomato, pepper, eggplant) or other host plants in the rotation. Rotate with cereals and grasses wherever possible
- Avoid fields with a long history of *Fusarium wilt*
- Plough the fields deeply and leave them fallow for 2–3 months, where feasible
- Use certified, disease-free seeds
- Use resistant varieties, for example tomatoes varieties such as 'Diego', 'Duke', 'Floridade', 'Fanny', 'Fortune Maker', 'Napoli', 'Radja', 'Roma VF', 'Roma VFN' and 'Tengeru 97'. Graft tomato plants on resistant root stocks where available
- Raise soil pH by applying lime, farmyard manure or good compost where soil is acidic. Do not use chicken manure. It is very acidic
- Control root-knot nematodes
- Keep fields weed-free
- Regularly irrigate the crop

3.3.1.2.5. Remedies

Effective Microorganisms (EM), Indigenous Microorganisms (IM)
Fungal diseases are successfully treated with the application of beneficial microbes, such as EM and IM.

For more information see 5. Common control methods for pests & diseases

3.1.1.3. Rhizoctonia

3.3.1.3.1. Scientific and common names

Pythium spp., Rhizoctonia solani (Thanatephorus cucumeris).
Damping-off diseases

3.3.1.3.2. What it is

Many fungi are associated with damping-off diseases and seedling blights. The species most often encountered belong to *Pythium spp.* and *Rhizoctonia spp.* For the two, an excess of moisture is recognised as the most important condition for damping-off and seedling blights.

Infection by *Pythium spp.* and *Rhizoctonia spp.* is favoured by:

- Heavy soils
- Low pH
- Heavy seeding resulting in dense planting
- Careless handling
- Excessive soil moisture
- Low light and presence of weeds

Exudates derived from host plants stimulate growth of these fungi.

Other fungi also implicated in causing damping-off and seedling blights include *Aphanomyces spp., Alternaria spp., Botrytis cinerea, Colletotrichum spp., Fusarium spp., Helminthosporium spp., Phytophthora spp., Sclerotinia spp. and Thielaviopsis spp.*

One feature that many of the fungi concerned have in common is their ability to survive for relatively long periods in soils.

There are several forms in which they do so:

1. As mycelium in the soil *(e.g. Rhizoctonia spp.)*
2. As resting spores (e.g. oospores of *Pythium spp.* and *Phytophthora spp., chlamydospores of Fusarium spp.)*
3. As sclerotia (tiny brown resting fungal bodies) *(e.g. Sclerotinia spp., Rhizoctonia spp.* and *Botrytis cinerea).*

The spread of damping-off fungi depends primarily on the mechanical transfer of mycelia, sclerotia, or resting spores in infested soil particles (on flats, tools, baskets or end of the watering hose) or infected plant tissue.

3.3.1.3.3. The damage caused

Damping-off is caused by fungus and usually occurs in small patches at various places in the seedbeds or field. The disease spots often increase from day to day until the seedlings harden. Seedlings are extremely susceptible for about two weeks after emergence. As the stem hardens and increases in size, the injury no longer occurs. Some seedlings are not killed at once, but the roots are severely damaged and the stem is girdled at the ground level. Such plants remain stunted and do not often survive transplanting.

There are two types of injury that result from damping-off fungi:

1. Pre-emergence damping off consists of a decay of the germinating seed or death of the seedling before it can push through the soil. This injury is a common cause of poor stands, which are often attributed to inferior quality of the seed or the untreated seeds. *Pythium spp. and Phytophthora spp.* cause seed decay.

2. Post-emergence damping-off which occurs after the seedlings have emerged from the soil. The roots may be killed and affected plants show water soaking and shriveling of the stems at the ground

level; they soon fall over and die. Post-emergence damping-off is mostly caused by *Rhizoctonia spp.*

Host range

The fungal disease caused by *Rhizoctonia solani* has a very wide host range, infecting plant species belonging to 32 families and 20 weed species from 11 families.

Rhozoctonia in chilli field

Rhozoctonia on ground nut

Rhozoctonia on seedlings

Symptoms

In crucifers, this fungus causes damping-off and wirestem of seedlings in the seedbed; bottom rot and head rot in the field; and storage and root rot of horseradish, radish, rutabaga and turnip.

- *Damping-off*
  Seeds can decay in cold wet soils and stems can become light brown and water-soaked near the soil line. Such seedlings wilt, topple and die. Wet soils and temperatures at or over 24°C favour disease development.

- *Wire stem in cabbage*
  This is the most common and destructive phase of the disease. The stem above and below the soil line shrivels and darkens and outer tissues come off leaving a dark wiry and woody inner stem. Such plants do not fall over, but they have an unhealthy stunted appearance. Some may die, but most survive and do poorly when transplanted to the field. When moisture is adequate, plants may produce a small poor-quality head.

- *Bottom rot in cabbage*
  The disease occurs in mid-season as a carry-over from wirestem seedlings and from new infections that occur when outer leaves come into contact with moist infested soil. Lower leaves wilt, decay and turn black, but do not drop off. Some plants may recover and produce heads, but usually bottom rot develops into head rot.

- *Head rot in cabbage*
  A firm to slimy dark decay at the base of the outer leaves in cabbage heads develops during the period between head formation and maturity. The fungus grows up to the main stem, passing between the leaf petioles. Foliage leaves die and drop off, exposing the stem beneath the

head. Over the whole head surface, brown fungus mycelia and tiny brown resting fungal bodies (sclerotia) may develop and be visible. Secondary rot bacteria usually invade the diseased tissue and turn the head into a slimy foul-smelling mass.

- *Root rot*
  It is usually dark brown, sunken and spongy. Infected tissues easily separate from advancing edges of the rot. A white to brown surface mould and irregular brown sclerotia distinguish this rot from other root rots. It mainly affects horseradish, radish, rutabaga and turnip.

Affected plant stages

Heading stage (in cabbage), post-harvest (in cabbage), pre-emergence, seedling stage and vegetative growing stage

Affected plant parts

Leaves, roots, seeds, stems and whole plant

Symptoms by affected plant part

Leaves: Lesions; abnormal colours; abnormal forms; wilting; fungal growth
Roots: Lesions
Seeds: Rot; discolourations
Stems: External discolouration; canker; abnormal growth; mycelium visible
Whole plant: Plant death; dieback; damping-off

3.3.1.3.4. Cultural practices to prevent its occurrence

General disease prevention

- Practice good seedbed management
- Avoid fields with a history of the disease
- Practice crop rotation
- Plough fields deeply
- Use certified disease-free seeds. If using your own seed, a hot water treatment can be used. For more information on hot water seed treatment, *see 5. Common control methods for pests & diseases*
- Solarisation of seedbeds should be done where feasible. For more information *see 5. Common control methods for pests & diseases*
- Thin seedlings in seedbeds to permit good air circulation
- Avoid excessive watering and fertilisation, particularly with nitrate
- Plant on raised beds to reduce moisture content in the root zone and provide the appropriate drainage in the field to prevent waterlogged conditions
- Schedule planting times to avoid temperature and moisture conditions that are conducive to the pathogen. It will also reduce disease severity
- As free water is important for distribution and development of the diseases, efforts to reduce soil moisture will help to reduce disease severity

Additional measures for:

- **Tomatoes:** The seedbed should not be sited on a field previously planted with eggplant, peppers, potatoes, tomatoes or other related crops. Do not site the seedbed next to or near to tomato production fields. The seedbed should preferably be up-wind to tomato fields
- **Brassicas:** Seedbeds and production fields should not have had crucifers for at least 3 years. All seedlings with wirestem symptoms should be discarded. During cultivation, take care to avoid throwing soil into plant heads
- **Okra:** Avoid fields previously planted with cotton or other related crops

3.3.1.3.5. Remedies

- Products of the soil fungus *Trichoderma spp.* are reported to suppress damping-off fungi
- Beneficial Microbes, such as EM & IM are reported to suppress damping-off fungi

3.3.1.4. Phytophthora

3.3.1.4.1. Scientific and common names

Phytophthora infestans
Late Blight, potato blight

3.3.1.4.2. What it is

Late blight of potato and tomato is caused by the fungus *Phytophthora infestans*. Although late blight can occur at any time during the growing season, it is more likely to be seen during cool, wet seasons. The disease can spread rapidly during cool, rainy weather, killing plants within a few days. Daytime temperatures of between 15° and -21°C, night temperatures of between 10° and 15°C and relative humidity near 100%, create ideal conditions for infection and spread of the disease. The fungus becomes inactive during dry periods.

The late blight fungus survives in infected potato tubers in the ground or in cull piles and in infected tomato fruits and crop debris. The fungus can also survive in perennial weeds, such as nightshade. As infected tubers and perennial weeds germinate and grow, the fungus becomes active and reproduces on the young plants.

Disease transmission

Spores are the mechanism for the rapid and devastating spread of late blight when conditions are cool and moist. Splashes of water can transfer the spores from plant to plant and wind can carry the spores over greater distances. If Irish potatoes have been grown in a field, infected tubers remaining in the soil after harvest can be a source of the disease for crops that follow.

Host range

Late blight is a fungal disease that can affect many vegetables of the Solanum species, mainly potatoes and tomatoes, but also eggplants. Late blight of potatoes or tomatoes can be devastating with dramatic and disastrous economic consequences. It is known as the most devastating disease of potatoes.

When conditions favour development of late blight and there are no steps taken to suppress the disease, it can completely destroy the above-ground parts of plants (stems, leaves, tomato fruits) and can also affect potato tubers.

3.3.1.4.3. The damage caused

Symptoms

Late blight symptoms can develop on leaves, stems, and branches and in the case of tomatoes, on both green and ripe fruits. In potatoes, tubers can also be infected. On leaves, pale green to brown spots, sometimes with a purplish tinge, appear on the upper surface of leaves. Leaf spot margins often are pale green or water-soaked. The spots may enlarge rapidly until entire leaflets are killed. In moist conditions, a downy white greyish mould usually develops near the margin of leaf spots on the underside of leaves. In dry weather, affected foliar parts may appear dry and shriveled. Stems can also develop elongated, greyish watery brown lesions.

On tomato fruit, grey green watery spots can develop on the upper half of the fruit, which later spread and turn greasy brown and bumpy. In moist weather, a white downy fungal growth may appear on the affected fruit-rot surface. Infected potato tubers exhibit wet and dry rots.

Late blight symptoms can be mistaken for several other diseases. Late blight is sometimes confused with early blight *(Alternaria solani)*. Early blight symptoms are more circular, larger and darker than late blight markings and have definite concentric (zonate) margins. Active late blight spots are not zonate and typically do not have definite concentric rings.

Phytophtora on potatoes

Phytophtora on tomatoes

Patches of infected plants have a characteristic odour as a result of the rapid breakdown of plant material.

Affected plant stages

All stages

Affected plant parts

All parts

Symptoms by affected plant part

Fruits: Spots, unusual odour
Leaves: Spots; abnormal colours; wilting; fungal growth
Vegetative organs: Leaf necrosis, dry rot
Whole plant: Seedling blight; leaf necrosis

3.3.1.4.4. Cultural practices to prevent its occurrence

Controlling blight once it has taken hold is very difficult. The most effective way of controlling late blight is to prevent its spread. Cultural techniques can help to reduce the risk of late blight outbreaks. Stake tomato plants to keep them off the soil, mulch to reduce water splashes and remove or dig old crops in deeply after harvest. Pruning of indeterminate tomato varieties will increase air movement and allow for good spray penetration. Irrigating in the heat of the day should allow the crop to dry before nightfall and reduce disease transmission and development.

Further cultural measures are:

Use healthy seeds/planting material

Use only tomato seeds/transplants and potato tubers that are certified disease free. Growing healthy plants helps to prevent disease in crops.

It is recommended to add compost or well decomposed animal manure and sowing green manures helps to improve soil structure and nutrient content to produce a healthier crop that can tolerate/or resist blight.

- **Field sanitation**

Eliminate all early disease inoculum by destroying crop residues such as potato cull piles and tomato debris, prevent growth of volunteer potatoes and planting tomatoes as far as possible from potatoes. Remove crop residues after harvesting.

- **Crop rotation**

Rotation away from tomatoes and potatoes for 3 to 4 years helps to break the disease cycle. Do not plant potatoes near tomatoes or other solanaceous crops when disease has occurred, as the disease can easily spread from one crop to another. Rotation will only be effective if it is done in cooperation with neighbouring farmers since the fungal spores of late blight can wind travel quite large distances.

- **Proper plant spacing**

Allow proper aeration among the plants and proper sunlight penetration. Indeterminate tomato varieties should be pruned and staked.

- **Resistant varieties**

In some agro-ecosystems, cultivars with tolerance are available and these could significantly reduce late blight damage. Ask your agricultural extensionist for information on recommended varieties for your locality.

- **Tool hygiene**

Clean tools thoroughly before using in a different area of crops to stop the disease from spreading. It is advisable to start field operations in clean fields and end-up in diseased fields. This would reduce spread of the disease on the farm.

- **Solarisation**

High temperatures have been used to control *Phytophthora* in many ways. Steam heat was used many years ago to kill Phytophthora in contaminated soil in greenhouses in the developed / first world countries. Although the industry now uses soil-less media, homeowners can still use this technique. Solar heating is achieved by laying out clear polyethylene tarps in the field. This helps pasteurise the soil. This method has been useful in places with a large proportion of cloudless days.

- **Weather forecasts**

Listen to weather forecasts (where such forecasts are broadcasted) on possible late blight outbreaks or ask for updates from your local agriculturists. The temperature-humidity rule is one of the methods used to forecast a late blight epidemic. Late blight fungus will sporulate (produce spores) when there is a cool and warm temperature that is not less than 10°C and where the relative humidity is over 75% for 2 consecutive days.

- **Potato: Use healthy seed tubers**

Late blight has not been reported as seed-borne on true seeds of potato. However, it is seed-borne on tuber seed pieces. For this reason, for potato crops, it is important to plant certified disease-free tubers.

- *How to select healthy potato tubers*

  The first plant parts to be inspected should be the seed tubers. Lesions can be readily seen on clean tubers with smooth white skins. Lesions are more difficult to detect on russeted or pigmented tubers. External inspection should be followed by observation of the flesh just underneath the potato tuber skin. Late blight causes a corky, ‘granular’, apparently discontinuous dry rot. Do not use these potato tubers for propagation.

  If you are not sure whether you have a healthy potato, the following test can be done:
  Take potato tubers out into the field or keep in a warm place for about 15- to 20 days before planting. Let them sprout at a temperature of between 15° and 20°C for 10 to 15 days. Diseased potato tubers will rot in high temperatures. Remove the rotten ones, dispose of them and select the healthy sprouted potatoes as planting materials.

- *Planting potato*

  Good soil coverage provides better protection for the potato tubers. Sow tubers in holes more than 15cm deep to protect them from easy infection. Hilling up the plant rows after germination will also reduce tuber infestation.

- *Post-harvest treatment of potato tubers*

  Before harvesting potatoes, the tops should be cut and left to dry completely. Harvest potatoes when the vines are completely dead because the causal agent of blight will not survive in dead vegetation. Dry tubers and remove infected ones before storing to reduce additional losses from soft rot diseases.

- **Tomato: Seed-treatment**

You can dry tomato seeds for 3 days at about 22°C or oven-drying them for 6 hours at between 29.5° and 37.7°C. Sun drying is also recommended. After this time, the late blight pathogen will be eliminated and the seed can be used for propagation.

Farmers' experience – avoiding crop losses
Avoiding disease can be an effective disease management strategy:

Farmers in the Andes plant susceptible potatoes at high altitudes where low temperatures and low moisture reduce late blight pressure. However, this strategy is frequently used in such a way that farmers trade off yield potential for decreased risk of disease. One survey in Ecuador estimated that between 30 and 40% of potato production in a province in central Ecuador was done in the dry season to avoid late blight. Yields in the dry season are considerably lower.

Similarly, much of the potato production in the highlands of Ethiopia occurs during a period known as the "short rains". Yields are low during this period because of limited water supply, but the risk of losses due to blight is also reduced. Overall production in this country could be increased by the introduction of potato cultivars with tolerance/resistance to late blight that could be planted in the main rainy season.

Traditional farmers in Kenya use a mixture of Mexican marigold, nettle and *Plectranthus barbatus* (a beautiful blue flowered shrub commonly used for hedging and said to have particular fungicidal properties), to prevent outbreaks of late blight.

3.3.1.4.5. Remedies

Copper
There are many copper compounds used as fungicides. Recommended are copper products based on either copper hydroxide or oxychloride. *Copper fungicides are formerly accepted in organic farming provided that the number of applications is strictly followed and a proper soil amendment is observed to prevent copper accumulation and remain within permissible limits from the certifying authority.*

In wet weather, fungicide sprays should be applied as soon as the disease is observed or as soon as local experience suggests that weather conditions are favourable for disease development.

Crop scouting should be used as a guide in making a decision on whether to apply a fungicide. And when applying fungicides, safety procedures in application must be complied with, particularly, in the use of protective clothing. *Observe proper dosage and prescribed pre-harvest intervals.*

Effective Microorganisms (EM), Indigenous Microorganisms (IM)
Fungal diseases are successfully treated with the application of beneficial microbes, such as EM and IM.

For more information see chapter 5. Common control methods for pests & diseases

3.3.1.5. Verticillium

3.3.1.5.1. Scientific and common names

Verticillium genus, V. dahliae, V. albo-atrum and V. longisporum.
Verticillium Wilt

3.3.1.5.2. What it is

Symptoms are superficially similar to *Fusarium* wilts.

While *Verticillium* wilts often have the same symptoms of *Fusarium* wilts, *Verticillium* can survive cold weather and winters much better than *Fusarium*, which prefers warmer climates. The resting structures of *Verticillium* are able to survive freezing, thawing, heat shock, dehydration and many other factors. They are quite robust and difficult to get rid of. The one factor they do not tolerate well is extended periods of anaerobic conditions (such as during flooding).

Verticillium grow best between 20° and 28°C, but germination and growth can occur well below (or above) those temperatures. Water is necessary for resting structure germination, but is not as important for the spread of the fungus as in many other fungi. While not an environmental requirement for the fungus, stressed plants, often brought on by environmental changes, are easier to attack than healthy plants, so any conditions that will stress the plant but not directly harm the *Verticillium* will be beneficial for *Verticillium* wilt development.

3.3.1.5.3. The damage caused

Verticillium spp. attack a very large host range including more than 200 species of vegetables, fruit trees, flowers, field crops and shade or forest trees. Most vegetable species have some susceptibility. A list of known hosts is at the bottom of this page.

Symptoms

The symptoms are similar to most wilts with a few specifics to *Verticillium*. Wilt itself is the most common symptom, with wilting of the stem and leaves occurring due to the blockage of the xylem vascular tissues resulting in reduced water and nutrient flow. In small plants and seedlings, *Verticillium* can quickly kill the plant while in larger, more developed plants the severity can vary. There are times when only one side of the plant will appear infected. This is because once in the vascular tissues, the disease migrates mostly upward and not as much radially in the stem.Other symptoms include stunting, chlorosis or yellowing of the leaves, necrosis or tissue death and defoliation. Internal vascular tissue discolouration might be visible when the stem is cut.

Verticillium - Gerald Holmes, California Polytechnic State University at San Luis

Verticillium wilts - Gerald Holmes, California Polytechnic State University at San Luis

Verticillium wilt begins as a mild, local infection, which over a few years will grow in strength as more virile strains of the fungus develop. If left unchecked, the disease could become so widespread that the crop will need to be replaced with resistant varieties or planted with a new crop altogether.

In *Verticillium*, the symptoms and effects will often only be on the lower or outer parts of plants or will be localised to only a few branches of a tree. In older plants, the infection can cause death, but often, especially with trees, the plant will be able to recover, or at least continue living with the infection. The severity of the infection plays a large role in how severe the symptoms are and how quickly they develop.

3.3.1.5.4. Cultural practices to prevent its occurrence

There is no chemical control for the disease but crop rotation, the use of resistant varieties and deep plowing, may be useful in reducing the spread and impact of the disease. Remove stricken growth and sterilise pruning clippers (one part bleach to 4 parts water) between cuts. It is best to remove the entire plant and solarise the soil before planting again in the same location.

Use balanced, slow-release organic fertilisers – high nitrogen fertilisers should be avoided.

Control of *Verticilium* can be achieved by planting disease free plants in uncontaminated soil, planting resistant varieties and refraining from planting susceptible crops in areas that have been used repeatedly for solanaceous crops. Soil fumigation can also be used, but is generally too expensive over large areas.

In tomato plants the presence of ethylene during the initial stages of infection inhibits disease development, while in later stages of disease development the same hormone will cause greater wilt. Tomato plants are available that have been bred with resistant genes that will tolerate the fungus in their system, while showing significantly lower signs of wilting. *Verticillium albo-altrum*, *Verticilium dahliae and V. longisporum* can overwinter as melanised mycelium or microsclerotia within live vegetation or plant debris. As a result it can be important to clear plant debris to lower the spread of disease. *Verticilium dahliae* and *V. longisporum* are able to survive as microsclerotia in soil up to 15 years.

3.3.1.5.5 Remedies

Effective Microorganisms (EM), Indigenous Microorganisms (IM)

Fungal diseases are successfully treated with the application of beneficial microbes, such as EM and IM.

For more information see chapter 5. Common control methods for pests & diseases.

Products containing *Streptomyces lydicus*, a naturally occurring soil bacterium that is found in healthy soils can be applied as a soil drench or foliar spray. It establishes itself on roots and leaves and provides protection against *verticillium* and other root and foliar diseases.

3.3.1.6. Botrytis

3.3.1.6.1. Scientific and common names

Botrytis cinerea
Grey mould disease, Botrytis bunch rot

3.3.1.6.2. What it is

Botrytis cinerea (*"botrytis"* from Ancient Greek botrys (βότρυς) meaning *"grapes"* plus the Neolatin suffix - it is for disease) is a necrotrophic fungus that affects many plant species, although its most notable hosts may be wine grapes. In viticulture, it is commonly known as botrytis bunch rot; in horticulture, it is usually called grey mould.

Found on a wide range of plants (too many to mention), grey mould *(Botrytis cinerea)* is a fungal disease that travels quickly through gardens, especially during damp, cool to mild weather. It can be identified as greyish coloured soft, mushy spots on leaves, stems, and flowers and on produce. Spots may become covered with a coating of grey fungus spores, especially if humidity is high. Fruit or plants shrivel and rot and often develop black, stone-like sclerotia under rotted parts.

Grey mould is often found near the soil surface or in the densest areas of the plant canopy. It develops on wilted flowers first, and then spreads quickly to other parts of the plant. The disease may also occur in storage, causing rotting of harvested fruits and vegetables.

Grey mould overwinters on plants, in or on the soil and as sclerotia. Spores develop when conditions are optimal and are moved by wind or splashing water onto blossoms or young leaves, where they germinate and enter the plant. Spores require cool temperatures of between 7° and 15° C and high humidity (93% and above) to germinate. Germinating spores rarely penetrate green, healthy tissue directly, but can enter through wounds on growing plants. Cuttings are particularly susceptible to infection.

3.3.1.6.3. The damage caused

Symptoms

The fungus gives rise to two different kinds of infections on grapes. The first, grey rot, is the result of consistently wet or humid conditions and typically results in the loss of the affected bunches. The second, noble rot, occurs when drier conditions follow wetter ones and can result in distinctive sweet dessert wines, such as Sauternes or the Aszúof Tokaji. The species name *Botrytis cinerea* is derived from the Latin for "grapes like ashes"; although poetic, the "grapes" refers to the bunching of the fungal spores on their conidiophores and "ashes" refers to the greyish colour of the spores en masse. The fungus is usually referred to by its anamorph (asexual form) name, because the sexual phase is rarely observed. The teleomorph (sexual form) is an ascomycete, *Botryotinia fuckeliana*, also known as *Botryotinia cinerea*.

Botrytis cinerea affects many other plants. It has a negative economic impact on soft fruits such as strawberries and bulb crops. Unlike wine grapes, the affected strawberries are not edible and are discarded.

In greenhouse horticulture, *Botrytis cinerea* is known as a cause of considerable damage in tomatoes.

The infection also affects rhubarb, snowdrops and white meadowfoam and cannabis spp.

Botrytis - Howard F. Schwartz, Colorado State University, Bugwood.org

Botrytis on Onion - Howard F. Schwartz, Colorado State University, Bugwood.org

3.3.1.6.4. Cultural practices to prevent its occurrence

- Prune or stake plants to improve air circulation between plants. Make sure to disinfect your pruning equipment (one part bleach to 4 parts water) after each cut
- If growing indoors, use a fan to improve air flow
- Keep the soil under plants clean and rake up any fallen debris
- Add a good amount of organic compost or mulch under plants. Mulches will prevent the fungal spores from splashing back up onto the flowers and leaves
- Water in the early morning hours, or use a soaker hose, to give the plants time to dry out during the day
- Do not compost infected leaves or stems and thoroughly clean up garden areas in the fall to reduce over wintering sites for the fungal spores
- To minimise infection in strawberry fields, good ventilation around the berries is important to prevent moisture being trapped among leaves and berries

3.3.1.6.5. Remedies

Copper or sulphur based organic fungicides will help by protecting plants from infections. Apply these weekly, when spring weather is continuously cool and wet or if Botrytis has been a problem in the past.

A number of bacteria have been proven to act as natural antagonists to *B. cinerea* in controlled studies.

Broad spectrum bio-fungicides using *Bacillus subtilis*, that are registered for organic use, have shown to be helpful. It is completely non-toxic to honey bees and beneficial insects.

Fungal diseases are successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms).

3.3.1.7. Alternaria

3.3.1.7.1. Scientific and common names

Alternaria solani
Early blight

3.3.1.7.2. What it is

Early blight is one of the most common and serious diseases of potato and tomato plants and is caused by the *Alternaria solani* fungus. This fungus is universally present in fields where susceptible crops were grown, particularly in warm, dry areas. Infection first occurs during periods of warm, rainy, humid weather. Increased damage may occur by secretions of toxins by pathogens.

Early blight is sometimes confused with late blight. Late blight lesions are lighter, smaller and they do not have the circular ridged bands that early blight has.

Early blight overwinters on infected plant tissue and is spread by splashing rain, irrigation, insects and garden tools. The disease is also carried on tomato seeds and in potato tubers. In spite of its name, early blight can occur any time throughout the growing season. High temperatures, between 25° and 30° C and wet, humid conditions promote its rapid spread. In many cases, poorly nourished or stressed plants are attacked.

3.3.1.7.3. The damage caused

Symptoms

All above ground parts of the plant can be affected. In seedbeds, pre- and post-emergence damping-off occurs. On young seedlings, collar rot may develop – it is characterised by girdling of the stem at the base of the plant. Affected seedlings are stunted and may wilt and die. When older seedlings are infected, stem lesions (spots) usually are restricted to one side of a stem and become elongated and sunken on stems and leaf petioles.

Affected leaves exhibit brown spots with concentric rings. Leaf spotting first appears on the oldest leaves and progresses upward on the plant. Entire plants could be defoliated and killed.

Alternaria tomato leaf

Typical fruit spots occur at the stem-end as a rot that radiates out from the area of attachment between the calyx and the fruit. The spot is usually brown to black, firm, depressed and has distinct concentric rings.

Alternaria tomato

Seriousness of early blight is dependant on weather conditions and crop variety. Early blight can develop quite rapidly under humid, warm conditions and is more severe when plants are stressed due to poor nutrition, drought, nematode attack or a heavy fruit load. Tomato plants become more susceptible with age, particularly at fruiting. In tomato seedbeds, collar rot may appear almost simultaneously on many plants indicating contamination of seeds or soil. Infection of potato tubers occurs through natural openings on the skin or through injuries. Tubers may come in contact with spores during harvest and lesions may continue to develop in storage.

Affected plant stages

All growth stages

Affected plant parts

All parts except roots

Symptoms by affected plant parts

Fruits/pods: spots. leaves: spots
Stems: External discolouration

3.3.1.7.4. Cultural practices to prevent its occurrence

- Controlling early blight once it has established is very difficult. The best way of controlling early blight is attempting to prevent its establishment and further spread
- Use clean seed: Make sure that seeds/ tubers for sowing and planting are certified and not taken from plants that were previously infected by early blight. If possible, use potato and tomato varieties that are resistant to the disease
- Use plant varieties that are tolerant or resistant to early blight. Examples of tolerant / resistant tomato varieties include 'Floradade', 'Hytec 36', 'Julius F1', 'Rio Grande', 'Rossol', 'Summerset F1', 'Zeal F1' and 'Zest F1'
- Destroy crop debris after harvest. Plough under all the crop residues after harvest to physically remove the inoculum (infection) source from the topsoil. Also remove weeds as they may serve as alternate hosts. Burn the infected material and plant debris

- Prune or stake plants to improve air circulation between plants. Make sure to disinfect your pruning equipment (one part bleach to 4 parts water) after each cut
- Rotate crops. Fields should not be planted with tomato, Irish potato, or eggplant for at least 2 cropping seasons, since they are hosts to early blight. Also avoid planting new plots of these vegetables alongside old ones. Rotations with small grains, maize or legumes are preferable
- Avoid injury to potato tubers during harvesting and handling and harvest potato tubers when the soil is not wet and when the vines are dry
- Practice proper plant spacing and staking. Prevent tomato plants from soil contact and prune and stake indeterminate varieties to promote good air circulation. Mulch determinate tomato varieties
- Water management: Drip irrigation and soaker hoses can be used to help keep the foliage dry. Where possible, avoid over-head irrigation. Otherwise, irrigate early in the morning so that the canopy is dry in the evening. With Irish potatoes, furrow irrigation should not be used especially after tuber formation
- Soil management: Use plenty of compost or well decomposed animal manures. Maintain soil fertility at optimal levels as nitrogen and phosphorus deficiency can increase susceptibility to early blight. Excess nitrogen could also induce early blight infection

3.3.1.7.5. Remedies

Broad spectrum bio-fungicides using *Bacillus subtilis*, that are registered for organic use, have shown to be helpful. It is completely non-toxic to honey bees and beneficial insects.

Fungal diseases are successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms).

- **Hot water treatment of seeds**

  Hot water treatment of seeds, where own seeds are used, could help reduce the incidence of seed-borne infection by early blight. It will also take care of other seed-borne problems caused by pathogens such as *Phoma spp., Septoria spp.* and bacterial pathogens.

  Specified temperatures and recommended time for treatment should be strictly followed in order to maintain seed viability. Use a good thermometer or ask for assistance from qualified personnel from your local extension office.

  To make sure that the seed is not damaged, it is advisable to test the germination of 100 heat-treated and 100 untreated seeds.

- **Botanical fungicides**

  Botanical fungicides are derived from plants. Many plant products are said to have fungicidal properties. They are natural products and most of them break down quickly on the leaves or in the soil. However, there is very little information on their effective recommended dose applications, their impact on beneficial organisms or their toxicity to humans.

Fermented Marigold extract:
Ingredients: Whole flowering plant, soap and water. Fill a drum ½ to ¾ full of flowering plants. Leave to stand for 5 to 10 days. Stir occasionally. Strain before use. Dilute the filtrate with water at a ratio of 1:2. Add 1 teaspoon of soap to every litre of the extract (Stoll, 2000).

Onion bulb extract:
Ingredients: 50 g of bulb onion and 1 litre distilled water. Finely chop the onion. Add to water. Mix well andstrain. Spray the infected plant thoroughly, preferably early in the morning or late afternoon (Stoll, 2000).

For more information on plant extracts, including standard procedures for the preparation and application of plant extracts *see chapter 5. Common control methods for pests & diseases.*

- **Sulphur**
  Sulphur sprays are permitted as preventive fungicides in organic farming. Various commercial products can be used and some farmers report that it has a preventive effect on early blight (farmer experience in Kenya), but is very harmful to predatory mites.

- **Copper**
  If the problem of blight is serious, fungicide spraying may be required. Ensure that persons dealing with fungicides are trained on the safe use and handling of pesticides.

  There are many copper compounds that are used as fungicides. Most copper products are either based on copper oxychloride or copper hydroxide and are readily available in the market. Copper is accepted in organic farming provided that the number of applications is strictly followed and a proper soil amendment is observed to prevent copper accumulation.

Note: *Excessive use of copper based products can be detrimental to the soil. Constantly shake the sprayer during the application process to prevent the solution from clogging. It is advisable to use dry flowable copper products.*

3.3.1.8. Powdery mildew

3.3.1.8.1. Scientific and common names

Phyllactina spp./Leveillula spp./Erysiphe spp./Uncinula spp./Blumeria spp./Golovinomyces spp./Podosphaera spp./Sphaerotheca spp.

3.3.1.8.2. What it is

Even though there are several types of powdery mildew fungi, they all produce similar symptoms on plant parts. Powdery mildews are characterised by spots or patches of white to greyish, talcum-powder-like growth. Tiny, pinhead-sized, spherical fruiting structures that are first white, later yellow-brown and finally black may be present singly or in a group. These are the cleistothecia or over-seasoning bodies of the fungus.

Hosts: Individual species of powdery mildew fungi typically have a very narrow host range. Hosts include cereals, grasses, vegetables, ornamentals, weeds, shrubs, fruit trees and forest trees. Notable exceptions include maize, celery and carrots.

Genera of powdery mildew fungi and their host plants:

- *Phyllactina spp. (Ovulariopsis)* attack trees and shrubs
- *Leveillula spp. (Oidiopsis)* attack Solanaceae
- *Erysiphe spp. (Oidium)* attack cereals and legumes
- *Uncinula spp. (Oidium)* attack trees and shrubs
- *Blumeria spp. (Oidium)* attack grasses
- *Golovinomyces spp. (Oidium)* attack cucurbits and Compositae
- *Podosphaera spp. (Oidium)* and
- *Sphaerotheca spp. (Oidium)* attack Rosaceae

3.3.1.8.3. The damage caused

Symptoms

The disease is most commonly observed on the upper sides of the leaves. It also affects the lower sides of leaves, young stems, buds, flowers and young fruit. Infected leaves may become distorted, turn yellow with small patches of green and fall prematurely. Infected buds may fail to open.

Affected plant stages

Seeding, vegetative and reproductive stages

Affected plant parts

Leaves, petioles, stems and sometimes fruits

Powdery mildew on cabbage

Powdery mildew on upper surface of okra leaf

Source of infection and spread

The white powdery growth consists of large numbers of fungal spores, which are spread by wind. The disease can spread very rapidly. It is more prevalent in dry weather when humidity is high and nights are cool. The fungus survives from season to season in dormant buds. Flowering is the most critical stage for infection.

Conditions that favour development

The severity of the disease depends on many factors; the variety of the host plant, age and condition of the plant and weather conditions during the growing season.

Powdery mildews are severe in warm, dry climates. This is because the fungus does not need the presence of water on the surface of the leaf for infection to occur. However, the relative humidity of the air needs to be high for spore germination, which is why the disease is common in crowded plantings where air circulation is poor and in damp, shaded areas. Incidences of infection increase as relative humidity rises to 90%, but it does not occur when leaf surfaces are wet such as in a rain shower. Young, succulent plants are usually more susceptible than older plant tissues.

3.3.1.8.4. Cultural practices to prevent its occurrence

Plant resistant or tolerant varieties to powdery mildew; mango varieties for example vary in susceptibility to powdery mildew. Varieties such as ‘Apple’, ‘Alphonse’, ‘Boribo’, ‘Kent’, ‘Ngowe’ and ‘Zill’ are highly susceptible; ‘Haden’ and ‘Keitt’ are moderately susceptible; and ‘Sensation’ and ‘Tommy Atkins’ are resistant. Inquire about resistant varieties before purchasing. If resistant varieties are unavailable, do not plant in low, shady locations.

Once disease becomes a problem:

- Avoid late-season applications of nitrogen fertiliser to limit the production of succulent tissue, which is more susceptible to infection
- Avoid overhead watering to help reduce the relative humidity
- Remove and destroy all infected plant parts. For infected vegetables and other annuals, remove as much of the plant and its debris as possible after harvest. This decreases the ability of the fungus to survive to the next season. Do not compost infected plant debris. Temperatures in the compost often are not hot enough to kill the fungus
- Prune overcrowded plant material to help selectively to increase air circulation. This helps reduce relative humidity and infection

3.3.1.8.5. Remedies

Sprays of powdered kelp, potassium bicarbonate or sulphur based products will often control the disease.

Fungal diseases are successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms).

Botanical extracts of plants high in silica, like *Equisetum spp* (horsetail), *Urtica spp* (stinging nettle) sprayed onto the affected plants is effective. So is diluted low fat or fat free milk.

3.3.1.9. Downy mildew

3.3.1.9.1. Scientific and common names

Albugo spp., Bremia spp., Peronospora spp., Pseudoperonospora spp.

3.3.1.9.2. What it is

Several different fungi cause downy mildew disease on vegetables, fruits, ornamentals, forages, field crops and tobacco. These include *Albugo spp.* (crucifers), *Bremia spp.* (lettuce), *Peronospora spp.* (cabbage, tobacco, spinach, soybeans, alfalfa, onion, many ornamentals), *Plasmopara spp.* (grape and sunflower), *Pseudoperonospora* (cucurbits), *Peronosclerospora* (sorghum and maize), *Sclerospora* (grasses, millet) and *Sclerophthora* (maize, rice, wheat).

Downy mildew fungi are fairly host specific. The downy mildew fungus that infects one type of plant (e.g. rose) is not the same downy mildew fungus that infects another (e.g. grape). However, if you see downy mildew on one plant, then environmental conditions (such as cool, wet weather) are favourable for the development of downy mildews on a wide range of plants.

Downy mildew of grape, spinach and tobacco causes serious economic losses. It spreads rapidly through fields and is dependent on a wet, humid environment with cool or warm, but not hot, temperatures. A film of water is needed on plant tissue for spore germination and infection.

Conditions that favour development include:

- Cool, moist weather conditions
- Host weeds found in between the crops
- Crop residues in the field
- Poor plant aeration
- Overcrowding (planting in high densities)

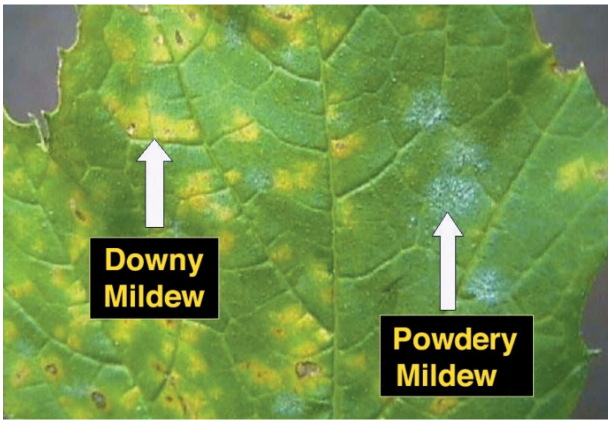
3.3.1.9.3. The damage caused

Symptoms

Plants can be infected at any time during their growing period. Symptoms of downy mildew infection include small, pale yellow spots with indefinite borders on the upper leaf surface. Purplish discolouration of the upper leaf surface is seen on some hosts. A downy growth (sporangiophores) may be seen directly under the spots on the underside of the leaf or on fruits or stems early in the morning or when foliage is wet. Young leaves and cotyledons may drop off when yellow.

Thus, the disease can cause severe damage to seedlings in the seedbed. Older leaves usually remain attached and affected areas enlarge, turning brown and papery. When the disease is severe, whole leaves die.

Downey mildew cabbage



Downy mildew - David B. Langston, University of Georgia, Bugwood.org

Downy mildew, lettuce - Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org

Affected plant stages

Seedling stage, vegetative growing stage, flowering stage and fruiting stage

Affected plant parts

Leaves and whole plant

Symptoms on affected plant part

Leaves: Lesions; fungal growth
Stems: Fungal growth
Flowers: Fungal growth; flower abortion; flower drop
Fruiting stage: Fungal growth

Damage caused by downy mildews is usually associated with the sporulation of the fungus. Sporulation of Peronospora destructor can cause up to 55% reduction in the dry weight of onion leaves (Yarwood, 1941). The corresponding figures for *Pseudoperonospora humuli* on hops and *Peronospora farinose* on spinach were 17% and 48%, respectively.

3.3.1.9.4. Cultural practices to prevent its occurrence

Prevention

- Use resistant varieties where available
- Use only certified disease-free seeds for sowing. Transplant only healthy seedlings
- Ensure proper land preparation to make sure that soil is well drained
- Provide adequate plant spacing to reduce the density of the canopy and minimise humidity
- Pruning of new growth also helps with plant aeration
- Remove infected plants and prune infected shoots
- Dispose of collected diseased-parts properly by either burning or burying them
- Avoid overhead watering. It lengthens the duration of leaf wetness and favours further development of the disease
- Plough-under all the plant debris after harvest
- Practice crop rotation

Control options

Control should be emphasised in nurseries since downy mildew is particularly damaging in the seedbed.

- Seedbeds should have well-drained soils and be sited away from hedges and windbreaks. The site should not have been under susceptible crops for at least the previous 2 years
- Seedlings should not be excessively watered
- Weeds should be eradicated in and near seedbeds and from production fields
- Crop residues should be removed from the field after harvest.
- Avoid sprinkler irrigation
- Thin plants to reduce plant density and increase air movement
- Time irrigations so that they do not elongate leaf wetness
- Alter planting dates to avoid periods of high disease pressure

3.3.1.9.5. Remedies

Fungal diseases are successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms).

- **Copper**

  There are many copper compounds that are used as fungicides. Most copper products are either based on copper oxychloride or copper hydroxide and are readily available in the market. Copper is accepted in organic farming provided that the number of applications is strictly followed and a proper soil amendment is observed to prevent copper accumulation.

Note: *Excessive use of copper based products can be detrimental to the soil. Constantly shake the sprayer during the application process to prevent the solution from clogging. It is advisable to use dry flowable copper products.*

- **Garlic bulb extract**

Ingredients: 50g of bulb garlic and 1 litre distilled water. Finely chop the garlic. Add to water. Mix well and strain. Spray thoroughly on the infected plant, preferably early in the morning or late afternoon (Stoll, 2000).

For more information on plant extracts, including standard procedures for the preparation and application of plant *extracts see chapter 5. Common control methods for pests & diseases.*

3.4. Bacterial diseases

3.4.1. Erwinia

3.4.1.1. Scientific and common names

Erwinia/Soft rot
Erwinia carotovora var.carotovora

3.4.1.1.2. What it is

Blackleg, aerial stem rot and tuber soft rot are caused by two closely related bacteria, *Erwinia carotovora subsp. atroseptica* and *Erwinia carotovora subsp. carotovora. E. c. carotovora* is very common and has an extensive host range, including most fleshy vegetables. It survives readily in soil and surface waters such as rivers, lakes and even oceans. These bacteria are capable of multiplying and persisting in the root zones of many host and non-host crops and weed species. In contrast, *E. c. atroseptica* is associated mostly with potatoes. These bacteria do not survive well in soil for more than one year, unless they are contained within diseased tubers or other potato plant debris. Blackleg is usually caused by *E. c. atroseptica*, carried on contaminated seed tubers. Most lots of seed tubers are contaminated to some degree, but the bacteria are usually dormant and do not cause disease unless environmental conditions are favourable. In contrast, aerial stem rot is usually caused by *E. c. carotovora* contained in infested soil or introduced to the crop by irrigation water, wind-blown rain and insects. Tuber soft rot can be caused by either of these soft-rot bacteria.

Moisture and temperature are the two critical factors in the initiation and development of soft-rot diseases. High soil temperatures and bruising of seed tubers favour seed-piece decay and pre-emergence blackleg. Blackleg in growing plants is favoured by cool, wet soils at planting followed by high temperatures after emergence. Dense plant canopies and long periods of leaf wetness favour infection of aerial plant parts. Although tuber soft rot can occur at any temperature above 10°C, disease develops best above 24°C. Oxygen depletion in tubers also favours soft rot. When seed pieces in soil or tubers in storage become covered with a film of water, the tissues rapidly become depleted of oxygen. This also may be induced by soil flooding or improper drying of washed tubers. Once it starts, tuber soft rot can proceed rapidly in storage. "Wet" areas may develop in the piled tubers that affect those below, spreading the bacteria. Heat, coupled with condensation on tuber surfaces, can further adversely affect storage conditions, resulting in the accelerated "melt" of the pile.

3.4.1.1.3.The damage caused

Symptoms

Blackleg begins from a contaminated seed piece, but the symptoms can occur at several stages of plant development. In severe cases, entire seed pieces and developing sprouts may rot in the ground prior to emergence, resulting in a poor stand. Blackleg often develops after plants are well established or even in flower. In this case, stem bases of diseased plants typically show an inky-black to light-brown decay that originates from the seed piece and can extend up the stem from less than an inch to more than two feet.

Leaves of infected plants tend to roll upward at the margins, become yellow, wilt and often die. Aerial stem rot (also called bacterial stem rot or aerial blackleg) is initiated by soft-rot bacteria from sources external to the seed piece.

Erwinia on cabbage

Stem infection can occur through wounds or through natural openings such as leaf scars. Lesions on diseased stems first appear as irregular brownish to inky-black areas. These enlarge into a soft, mushy rot that causes entire stems to wilt and die. Potato tubers with soft rot have tissues that are very soft and watery and have a slightly granular consistency. The diseased tissue is cream to tan-coloured and often has a black border separating diseased from healthy areas. In the early stages, soft-rot decay is generally odourless, but later a foul odour and a stringy or slimy decay usually develop as secondary-decay bacteria invade infected tissues. Most internal tuber tissues may be consumed by soft rot organisms, sometimes leaving only a shell of skin remaining in the soil.

Erwinia on potato - William M. Brown Jr., Bugwood.org

Erwnia on maize - Howard F. Schwartz, Colorado State University, Bugwood.org

3.4.1.1.4. Cultural practices to prevent its occurrence

- Plant only certified, disease-free seed tubers. If possible, use whole (B-size) seed tubers that do not have to be cut
- When receiving seed tubers in bags, do not stack more than five bags high. With bulk or bagged seed, store at between 4° and 7°C for 2 to 3 weeks before planting, then warm to between 13° and 15°C prior to cutting
- Clean all equipment used for cutting seed tubers thoroughly and then sanitise with a 10% bleach solution. Clean cutting equipment again periodically and definitely before cutting a new lot of seed tubers
- Treat cut seed pieces with recommended fungicide dressings immediately after cutting
- Plant treated cut seed pieces immediately if soil temperatures are between 13° and 18°C at planting depth. Seed pieces can be held for 1 to 2 weeks at between 13° and 16°C and between 95% to 99% relative humidity to hasten the healing of cut surfaces. Condensation on surfaces of seed pieces must be avoided
- Do not irrigate fields until plants are well emerged. Avoid using surface water for irrigation
- During crop growth, monitor irrigation and nitrogen fertility to minimise excessive vine growth that will promote leaf wetness within the plant canopy
- Harvest tubers only after the vines are completely dead to ensure skin maturity. Low spots in the field should be left unharvested if significant water-logging has occurred
- Take all precautions to minimise cuts and bruises when harvesting and handling tubers
- Hold newly harvested potatoes at between 13° and 16°C with 90% to 95% relative humidity for the first 1 to 2 weeks to promote wound healing. After this curing period, lower the temperature of table stock to between 3° and 5°C for long-term storage. Never wash tubers prior to storage

3.4.1.1.5. Remedies

Bacterial diseases have been successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms). Ideally the fields are inoculated with beneficial microbes before the crop is planted as well. For this to be effective the soil has to have good organic matter content as food for the microbes.

3.4.2 Bacterial Wilt

3.4.2.1. Scientific and common names

Ralstonia solanacearum (Pseudomonas solanacearum)

3.4.2.2. What it is

The bacterium is soil-borne and can survive in soil for long periods. However, some soils are conducive to bacterial wilt. Important soil factors affecting the occurrence and persistence of the pathogen are soil moisture and antagonistic microorganisms. Soil type influences soil moisture and population of antagonistic microorganisms, which in turn affect the survival of *R. solanacearum* in soil.

Bacterial wilt *(R. solanacearum)* has a very wide host range and infects all nightshade plants (members of *Solanaceae*). Weed hosts include black nightshade, lantana and Jimson weed. It infects plants through roots. As the roots of wilted plants decay, the bacteria are released back into the soil. The bacterium is especially destructive in moist soils at temperatures above 24°C. It is sensitive to high pH (alkaline soils), low soil temperature, low soil moisture and low fertility levels. Spread is affected by running water, movement of infested soil and also diseased seedlings.

Bacterial wilt can also be spread on vegetative propagating material. Therefore, plant quarantine of potentially infested plant material is very important to avoid long-range dispersal.

Conditions that favour disease development

Crop residues infected with *Ralstonia solanacearum* left in the field
Injured roots caused by farm tools or by soil pests
Warm temperature and high soil moisture.
Slightly acidic soils
Poor and infertile soil
Infestation by root-knot nematodes

R. solanacearum constitutes a serious obstacle to the cultivation of many solanaceous plants in both tropical and temperate regions. The greatest economic damage has been reported on potato, tobacco and tomato crops. It can sometimes cause total crop losses. Disease severity mostly increases if *R. solanacearum* is found in association with root nematodes. In tobacco, nematode infestation changes the physiology of the plants, causing susceptibility to bacterial wilt. Experiments in India showed that the combined pathogenic effects of *R. solanacearum* and root-knot nematodes *(Meloidogyne javanica)* were greater than the independent effects of either (CABI, 2005)

The bacterium is a quarantine organism. The occurrence of different races and strains of the pathogen with varying virulence under different environmental conditions presents a serious danger to potato and tomato production. Absence of the bacterium is an important consideration for countries exporting seed potatoes.

3.4.2.3. The damage caused

Symptoms

The disease causes rapid wilting and death of the entire plant without any yellowing or spotting of leaves. All branches wilt at about the same time. When the stem of a wilted plant is cut across, the pith has a darkened, water-soaked appearance. There is greyish slimy ooze on pressing the stem. In later stages of the disease, decay of the pith may cause extensive hollowing of the stem. Bacterial wilt causes no spotting of the fruits. Affected roots decay, becoming dark brown to black in colour and if the soil is moist, diseased roots become soft and slimy.

Water test: To distinguish this wilt from others, take a thin slice or sliver of the brown stem tissue. Cut a piece of the stem (2cm to 3cm long from the base). Suspend the cut stem in clear water in a glass container. Hold the stem with an improvised tong to maintain a vertical position. Within a few seconds, milky bacterial threads are discharged from the cut stem. If bacterial wilt is present, a milky bacterial stream (strands) flows from the lower cut surface of the sliver within seconds.

Bacterial wilt test

Bacterial wilt on potato

Bacterial wilt of potato: The infested leaves wilt during the day, especially if it's sunny and sometimes they recover during cool hours. The wilting is similar to the result of lack of water. During the rapid development of the disease, the entire plant wilts quickly without yellowing. Other symptoms could be wilting of only a part of the stem, or one side of the leaf/stem. The stem wilts or dries up completely and the remainder of the plant remains healthy. When the diseased tuber is cut, it shows a browning of the vascular ring and the immediate surrounding tissues. On the cut surface, a creamy fluid usually appears on the vascular ring.

Bacterial wilt on sweet pepper

Bacterial wilt of tomato/eggplant: The initial symptom is a wilting of the terminal leaves, which after 2 to 3 days becomes permanent when the whole plant wilts due to the active development of the disease. Then the whole plant wilts and dies suddenly. Total collapse of the plant usually occurs when temperatures reach 32°C and above. Plants wilt while still green. In the case of a slow development of the disease, the plant stunts and produces large numbers of adventitious roots on the stem. Bacterial wilt diagnosis in the field can be done easily.

Bacterial wilt of banana: Initially one of the youngest three leaves turns pale-green or yellow in colour and breaks down at the petiole and the pseudostem. Later, all the other leaves collapse around the pseudostem. An infected finger or fruit shows dry and rotted pulp that is coloured brown or black and the presence of bacterial discharges.

Affected plant stages

Vegetative growing stage

Affected plant parts

Leaves, roots, seeds, fruits, stems, vegetative organs and whole plant

Symptoms by affected plant part

Growing points: wilting
Leaves: wilting
Roots: rot
Stems: internal discolouration; creamy exudates; wilt
Vegetative organs: internal discolouration

3.4.2.4. Cultural practices to prevent its occurrence

- Crop rotation is not effective as the pathogen can survive for several years in the soil and also attack a wide range of crops and solanaceous weeds
- Use plant varieties that are tolerant/ resistant to bacterial wilt. The following tomato varieties have been claimed to be resistant to bacterial wilt; "Fortune Maker", "Kentom" and "Taiwan F1"
- Do not grow crops in soil where bacterial wilt has occurred
- Rogue out wilted plants from the field to reduce spread of the disease from plant to plant
- Control root-knot nematodes since they could facilitate infection and spread of bacterial wilt
- Where feasible, extended flooding (for at least 6 months) of the infested fields can reduce disease levels in the soil
- Soil amendments (organic manures) can suppress bacterial wilt pathogen in the soil.

Disease avoidance

Since high soil temperatures and soil moisture enhance bacterial wilt development, damages can be minimised by changing the date of planting, considering seasons which are less favourable for disease development.

Intercropping

In some developing countries, intercropping has been used as a means of reducing pathogen populations in the soil and root-to-root transmission.

In Burundi, growing potatoes with beans lowered the incidence of bacterial wilt, indicating that a bean intercrop, which has a dense root system and grows quickly, was better than a crop such as maize, which develops slower and has a more dispersed root system.

3.4.2.5. Remedies

Good results have been reported in Australia, the US and the Philippines on the use of "Biofumigation" as soil treatment for bacterial wilt.

Bacterial diseases have been successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms). Ideally the fields are inoculated with beneficial microbes before the crop is planted as well. For this to be effective the soil has to have good organic matter content as food for the microbes.

3.4.3. Black Rot

3.4.3.1. Scientific and common names

Xanthomonas campestris pv. campestris

3.4.3.2. What it is

Black rot affects cabbage and related crops (brassicas, mustard & radish) worldwide and is caused by the bacterium *Xanthomonas campestris pv. campestris*. Black rot is one of the most serious cabbage/kale diseases in warm climates. Diseased plants may rot quickly before or after harvest because of secondary infection from bacterial soft-rot.

Soft rot bacteria may invade heads of black rot infected plants, causing tissue to become slimy and foul smelling. The black rot bacterium can over-season on infected cabbage seeds, in weeds belonging to the Brassica family (including black mustard, field mustard, wild turnip, wild radish, shepherd's purse and pepper weed); or in infected plant material in the soil. The bacterium can persist in plant residue for 1 to 2 years or as long as the plant debris remains intact.

Black rot is a pathogen of most cultivated cruciferous plants and weeds. Cauliflower and cabbage are the most readily affected hosts in the crucifers, although kale is almost equally susceptible. Broccoli and Brussels sprouts have intermediate resistance and radish is quite resistant, but not to all strains. Kohlrabi, Chinese cabbage, rutabaga, turnip, collard, rape, jointed charlock *(Raphanus raphanistrum)* and mustard are also susceptible hosts.

The bacteria survive in infected seed, in debris from diseased plants left in the field and in infested soil. Seed-borne bacteria can be disseminated over long distances. Many cruciferous weeds can harbour the black rot bacteria. In a new field, black rot is usually introduced via infected seed or diseased transplants.

Further spread is facilitated by water-splash, running water and by handling infected plants. The bacteria enter the plant mainly through water pores at the edges of leaves. They can also enter through the root system and wounds made by chewing insects. They then move through the water vessels to the stem and the head. Black rot grows in warm - between 26° and 30°C and wet conditions.

3.4.3.3. The damage caused

Symptoms

The plant can be infected at any time during its life cycle. Yellowing appears on young seedlings along the margin of the cotyledons, which later shrivels and drops off. Similar yellowing appears on the margins of mature leaves. Initially, a small V-shaped area develops, but as the diseased area enlarges, the veins become distinctly black. In contrast to *Fusarium* (yellow) the veins are brownish in colour. The affected stem, when cut crosswise, shows a characteristic black ring. In later stages of the disease, the entire head may turn black and soft due to secondary infection by soft rot bacteria *(Erwinia carotovora var.carotovora)*.

Black rot on cabbage

Black rot affecting water conducting tissue of a stem

Affected plant stages:

Seedling stage, vegetative growing stage and heading stage (cabbages)

Affected plant parts:

Leaves, seeds, stems, vegetative organs and whole plant

Symptoms by affected plant part:

Leaves: 'V' shaped lesions
Seeds: discolourations; lesions
Stems: Internal discolouration (black in colour)
Vegetative organs: internal discolouration (black in colour); dry rot
Whole plant: plant death

3.4.3.4. Cultural practices to prevent its occurrence

Control options

- Use certified disease-free seed
- Establish crops in black rot-free soils that have not grown crops from the family Crucifers for at least 3 years
- Seedlings should not be crowded in the nursery
- Transplants should not be dipped in water before transplanting
- Mulching of the field crop, where practicable, is highly recommended
- Avoid wet, poorly-drained soils
- Avoid overhead irrigation
- Field operations during wet weather should be discouraged
- Keep the field free of weeds, particularly of the crucifer family
- Growing cabbage on raised beds helps eliminate conditions that induce black rot
- When possible, remove, burn, or plough down all crop debris immediately after harvest to reduce the amount of bacteria in the soil
- A crop rotation based on at least a 2-year break in cruciferous crops is advocated
- Use of resistant/ tolerant varieties, where commercially available, provides the most effective control of the disease

3.4.3.5. Remedies

Bacterial diseases have been successfully treated with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms). Ideally the fields are inoculated with beneficial microbes before the crop is planted as well. For this to be effective the soil has to have good organic matter content as food for the microbes.

Apply hot water seed treatment for possible contaminated seeds, before planting.

For more information see chapter 5. Common control methods for pests & diseases

3.5. Viral Diseases

3.5.1 African Cassava Mosaic Virus (ACMV)

3.5.1.1. Scientific and common names

Order/Family: *Geminiviridae: Begomovirus {GEM2}*

3.5.1.1. What it is

Cassava *(Manihot esculenta)* and castor bean *(Ricinus communis)* are the two major hosts of ACMV. Wild hosts are other plants of the family *Euphorbiaceae* (for example wild poinsettia, garden spurge).

ACMV is the most important single factor limiting cassava production. Its wide distribution in the region is primarily due to the use infected planting material, the widespread presence of the vector *(Bemisia tabaci)* and the use of traditional local varieties that are susceptible to the virus. During the 1990s, a pandemic of an unusually severe form of the disease expanded to cover a large part of East Africa, southern Sudan and eastern Democratic Republic of Congo. This has been associated with the occurrence of a novel and highly virulent cassava mosaic begomovirus the "Ugandan variant" of East African cassava mosaic virus (EACMV-UG). (Legg et al., 2005).

African Cassava Mosaic Geminivirus (CMGV) is a vector-borne virus, transmitted by the whitefly (*Bemisia tabaci)* and disseminated in cuttings derived from infected plants.

Cassava is the major CMGV reservoir and possibly the main host of whitefly vectors. Whiteflies are carried by the prevailing wind and can spread the virus over distances of several kilometres from cassava fields. Even a single whitefly can transmit the virus. Whiteflies prefer to feed on young leaves. Virus spread, cassava growth and whitefly populations are dependent on climatic factors. Also, seasons of rapid spread coincide with periods of rapid cassava growth and population of whiteflies carrying the virus. Crop growth in turn, depends on radiation-associated factors in humid conditions or to rain-associated ones in drier environments. Cassava varieties also differ greatly in their susceptibility to the virus (Farguett and Thresh 1994).

3.5.1.3. The damage caused

Symptoms

African Cassava Mosaic Virus is the most important virus disease of cassava, but total losses are extremely difficult to estimate. For example, while cassava yields are only 9 tons per hectare in Association for strengthening Agricultural Research in Eastern and Central Africa (ASARECA) region, yields in India average at about 25 tons per hectare. Yield losses with individual cultivars have been reported from different countries to range from 20% to 95% (Seif, 1982). Losses depend on variety and crop growth stage at infection, but are usually substantial. In Côte d'Ivoire, total losses were estimated to be 0.5 million tonnes per year compared with actual production at the time of 0.8 million tonnes.

African cassava mosaic virus ACMV on the leaves of a cassava cultivar

3.5.1.4. Cultural practices to prevent its occurrence

- Remove all infected cassava or other host plants from within and around sites to be used for new plantings
- Use virus-free stem cuttings for all new plantings
- Use tissue culture derived planting material
- Use cassava varieties which are resistant and/or tolerant to mosaic virus. For example, varieties derived from IITA, Nigeria, such as TMS 30337, TMS 30395, TMS 30572, TMS 60142, TMS 30001 and TMS 4(2)1425) have been widely distributed in Africa and are now grown by producers in many of the main cassava-producing countries in Africa
- If it is not possible to find cassava plants that are completely free from the disease, select cuttings from stem branches instead of the main stem. Stem cuttings from the branches are more likely to sprout into disease-free plants than stem cuttings from the main stems (James et al, 2000). Also, it has been found that growing of mixture of varieties in the same field aids in the reduction of virus transmission (Legg et al, 2005)

- Remove diseased plants from within crop stands (roguing)

Roguing is a well-known means of virus disease control and it is only advocated when disease incidence is low (less than 5%). It has been often recommended to control the African cassava mosaic virus.

Rogue once or twice soon after planting, when any infected cuttings develop shoots expressing obvious symptoms. Roguing is more effective when practiced by farmers' groups and throughout whole localities. Frequent roguing is ineffective where there is a high spread of the virus to susceptible varieties. Inspect cassava plantings at least once a week for the first 2 to 3 months of growth to find and remove immediately any occurring diseased plants

Field size and shape

Virus incidence and whitefly numbers tend to be greatest in the outermost rows of plantings, especially the ones oriented across the prevailing wind. To prevent or reduce the incidence of ACMV:

- Plant in large, compact blocks
- Orientate elongated plots along the prevailing wind, rather than across, so that fewer plants are exposed
- Use the outermost rows to raise virus-free cuttings for distribution, or plant a resistant variety of cassava around the field margins

Crop disposition

The main spread of cassava mosaic virus is into and not within plantings. Thus, you can facilitate control by selecting suitably isolated sites where the risk of infection from an outside source is limited. There is little information available on the minimum isolation distance needed for effective infection control.

The risk of infection is much higher where sources of infection are upwind and nearby than when the nearest sources are downwind and remote. Thus, spread can be decreased by planting sequentially in an upwind direction from the source.

Crop spacing

Studies in Uganda and the Ivory Coast showed that the spread of cassava mosaic disease is influenced by host-plant population density and disease incidence was highest at the widest spacing between cassava stands and along footpaths or gaps in the stands. Thus, using uniform dense cassava stands rather than irregular widely spaced ones can help reduce disease incidence.

Planting date

You can facilitate the control of the cassava mosaic virus by avoiding exposition of vulnerable young plants to risk of infection in times when whiteflies are most abundant. Cassava grows readily from stem cuttings, enabling planting throughout much of the year, especially where there is enough rainfall.

Soil fertility and nutrient status

Cassava is able to grow in harsh environments. Plantings are often made in poor soils or after more nutrient-demanding crops. Studies in Uganda showed that poor soil may enhance damage caused by the virus: damage was most severe in the north, where soil conditions and rainfall are generally less favourable than in the south.

In Zanzibar, cassava grown on fertile land was less affected by the disease than on less fertile soils.

Intercropping

In many parts of Africa, cassava is usually grown with other crops including banana, sweet potato, cereals and legumes. Intercropping may improve overall land productivity and may decrease whitefly vector populations, whitefly activity and virus spread.

However, intercropping is more likely to complement rather than replace other more effective control measures.

Plant many varieties
Studies in Uganda showed that in areas where many varieties of cassava were grown, losses were much less than when only one variety was planted. Also, disease incidence in a susceptible variety was lower when mixed with resistant varieties than when it was grown alone.

3.5.1.5. Remedies
No known remedies.
Control of whitefly will remedy the disease indirectly. *See 3.6.3.White Fly for details.*

3.5.2. Tomato Yellow Leaf Curl Virus Disease (TYLCV)

3.5.2.1. Scientific and common names

Order/Family: *Geminiviridae: Begomovirus {GEM2}*

3.5.2.2. What it is
The TYLCV is not seed-borne and is not transmitted mechanically. The disease is spread by whiteflies *(Bemisia tabaci)*. Whiteflies have a wide host range. New plant growth attracts whiteflies, which feed on the lower leaf surface. It takes about 15 to 30 minutes for the whitefly to become infected by the virus. The incubation period is between 21 and 24 hours and the transmission period at least 15 minutes.

Factors that favour development:

High temperatures and low or no rainfall
Presence of whiteflies
Infected transplants
Weedy fields

The disease can be easily recognised when tomato plants are infected at the seedling stage. TYLCV causes severe stunting of young leaves and shoots, resulting in bushy growth of infected seedlings.

Tomato plants infected early in the season are normally stunted and excessively branched. Such plants have terminal and axillary shoots erect while leaflets are reduced in size and abnormal in shape.

Affected leaves are curled upwards or inwards. Flower drop is common and therefore infected plants have a reduced number of flowers and fruit. If infection takes place at a later stage of growth, fruits already present develop normally. There are no noticeable symptoms on fruits derived from infected plants. Generally, table tomatoes are severely affected by the disease, especially when infection occurs before the flowering stage.

Although TYLCV has a broad host range, it is primarily known as one of the most damaging viruses to infect tomatoes. Beans (*Phaseolus vulgaris*) are also hosts of TYLCV and show severe symptoms after infection by whiteflies. The virus has been reported from non-solanaceous plants like sesame *(Sesamum indicum)*, asthma weed *(Euphorbia geniculata)*, fleabane *(Conyza stricta)* and oxalis *(Oxalis corniculata* and *O. acetosella)*.

3.5.2.3. The damage caused
Affected plant stages

Seedling stage, generative and vegetative growing stage

Affected plant parts

Leaves, stems and the whole plant

Symptoms on affected plant part

Leaves: Stunting; bushy growth; reduced size; abnormal forms
Flowers: Drop
Stems: Abnormal growth
Whole plant: Dwarfing

The virus affects yields by greatly reducing the number of fruit produced. Fruit developing at the time of infection remain on the plant, but very few fruit will set once infection has occurred.

TYLCV causing multiple and thickened shoots

TYLCV visibly causing thickened shoots

3.5.2.4. Cultural practices to prevent its occurrence

- Avoid continuous growing of tomato crops. Practice crop rotation by planting crops that are not susceptible to whiteflies
- Use resistant/tolerant varieties like 'Amareto', 'Peto 86', 'Fiona F1', 'Perlina', 'Denise', 'Cheyenne (E448)', ‘Rover’
- Mulch the seedbeds and mulch tomato fields with sawdust or straw
- Protect seedbeds with a white nylon net (40 mesh)
- Pull out diseased seedlings
- Protect seedlings from whiteflies
- Plant barrier crops like maize around tomato fields. These crops should be sown a month or two before transplanting
- Remove infected-looking plants and bury them immediately
- Do not plant cotton near tomato and/or other crops susceptible to whiteflies or vice versa
- Eradicate weeds
- Plough-under all plant debris after harvest or burn them when possible

3.5.2.5. Remedies

No known remedies.

Control of whitefly will remedy the disease indirectly. *See 3.6.3.White Fly for details.*

3.5.3. Turnip Mosaic Virus (TuMV)

3.5.3.1. Scientific and common names

Order/Family: Potyviridae: Potyvirus

3.5.3.2. What it is

Turnip Mosaic Virus (TuMV) has a very wide host range infecting at least 318 species in 156 genera of 43 families. TuMV infects most cruciferous plants, but is most damaging in Chinese cabbage, turnip, mustard and radish. It also attacks beets, spinach and tobacco.

Transmission

TuMV is transmitted by aphids notably green peach aphid *(Myzus pericae)* and cabbage aphid *(Brevicoryne brassicae)* and is readily transmitted mechanically. The virus is transmitted by aphids in a non-persistent manner (short virus transmission period of 10 to 30 seconds) with no latent period (the time from start of an acquisition feeding until the vector can infect healthy plants with the virus).

It can be acquired in less than one minute and can be inoculated in less than a minute. The transfer of viruses by aphids usually occurs over short distances (up to a few hundred metres), particularly down-wind and involves migrating *alates* (winged aphids).

Weather conditions and temperature influence aphid activity and migration patterns which in turn affect dissemination of TuMV. Dry and warm conditions favour aphid reproduction and dissemination and consequently, early and increased spread of the virus. Cool, wet and windy conditions reduce the reproduction and movement of aphids and hence, the spread of the virus.

Once primary infections are established in fields, TuMV may spread relatively rapidly from plant to plant if aphids are not controlled. Seed transmission of the virus has not been observed.

Sources of Infection

Primary sources of TuMV infection are diseased host plants and weeds. Vectors can be introduced into field crops with infected transplants. Transplants can become infected during propagation in nursery beds. It is not seed transmitted.

3.5.3.3. The damage caused

Infected plants are stunted, with leaves coarsely mottled and distorted. Black spots develop on leaves which prematurely drop. Early infection of cabbage crops by this virus in the seedbed or soon after transplanting can reduce yield by 75%, whereas late-season infection has little or no effect on yield. It also reduces seed yield.

Affected plant stages

Flowering stage, fruiting stage, seedling stage and vegetative growing stage

Affected plant parts

Leaves, seeds, stems and whole plant

Symptoms by affected plant part

Leaves: Lesions; abnormal colours; abnormal patterns; abnormal forms; yellowed or dead
Seeds: Empty grains; lesions
Stems: External discolouration; abnormal growth; dieback
Whole plant: Plant dead; dieback; dwarfing; early senescence

Symptoms

On cabbage: Mosaic, black speckling or stippling of cabbage heads at harvest or during storage can be caused by the TuMV or the cauliflower mosaic virus occurring singly or together. The latter causes lumpy or warty growths on the veins on the under surface of leaves and vein clearing. In stored cabbage, black sunken spots develop on leaves throughout the head. The spots are considerably larger than those caused by cauliflower mosaic virus. Its mode of transmission is similar to TuMV (i.e. aphids and mechanically). However, cauliflower mosaic virus has a restricted host range. It is infectious only to members of the cabbage family *(brassicas)*.

TuMV - David B. Langston, University of Georgia, Bugwood.org

TuMV - Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org

3.5.3.4. Cultural practices to prevent its occurrence

Control of TuMV is quite difficult due to the very wide host range of the virus, the ineffectiveness of insecticides in controlling the spread of non-persistently transmitted viruses and the lack of immune crop cultivars.

Locate seedbeds away from weedy fields. Weeds and volunteer plants should be eliminated from seedbed areas and preferably from production fields. It may be helpful to discard plants from outside rows in seedbeds. A very common method of transferring the virus from plant to plant is on contaminated hands and tools. Wash your hands frequently and thoroughly with soap and water when transplanting seedlings. Field equipment should be used in new fields first and then in older fields. Never attempt to transplant a healthy plant into the soil, from which a diseased plant was removed. Roots from diseased plants will remain in the soil and provide the virus with a source of nutrition before the new transplant. Field sanitation, particularly, weed control is very important since the virus can infect many weed species.

In areas where TuMV is serious and endemic, growing Danish cabbage varieties should be considered. These varieties have been reported to have some resistance to TuMV (Sherf and Macnab, 1986).

3.5.3.5. Remedies

There are no known remedies.

3.6. Insects

3.6.1. Spider mite

3.6.1.1. Scientific and common names

Tetranychus spp., Mononychellus spp., Oligonychus spp

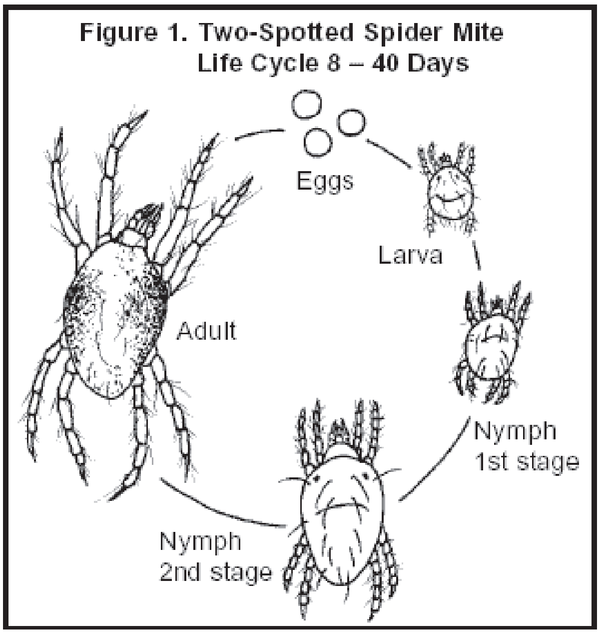
3.6.1.2. What it is

Mites are not insects. They are related to spiders and ticks and they are very tiny (they rarely exceed a size of 0.5mm). Spider mites are normally active within a temperature range of 16°C to 37°C. They are more prevalent in hot, dry weather and less so after rains. Wind plays an important role in the dispersal of spider mites. The lifecycle of a spider mite may take 10 to 30 days, depending on temperature. It includes five stages: egg, larva (first instar) two nymphal stages and adult. A female may lay over 100 eggs during its lifespan. Spider mites spin silk threads that anchor themselves and their eggs to the plant. This silk protects them from some of their enemies and even from pesticide applications.

Eggs are tiny, spherical, pale-white and are laid on the undersides of leaves, often under the webbings and can only be seen with a magnifying lens. Eggs hatch in 4 to 5 days.

The larvae are light green or pinkish, slightly larger than the eggs and have six legs.

The nymphs look similar to the adults but are smaller. They are green or red in colour and have eight legs.



life cycle of spider mite -www.agf.gov.bc.ca

Spider mite damage on tomato

Spider mite on tomato leaf

The adults are oval and have eight legs. They are very tiny (they rarely exceed a size of 0.5mm), resembling tiny moving dots to the naked eye. The male is usually smaller than the female and has a more pointed abdomen. Spider mites vary in colour depending on the species. Many of the species are bright red and why they are sometimes referred to as red spider mites. Others are yellowish, greenish, pinkish, orange or reddish in colour. The two-spotted spider mite has a large dark blotch on each side of the body.

Spider mite on tomato with visible web between leaves

Major species of spider mites in Africa:

- The common/two-spotted spider mite *(Tetranychus urticae)*
- The tobacco red spider mite *(Tetranychus evansi)*
- The carmine red spider mite or common red spider mite *(Tetranychus cinnabarinus)*
- The cassava green mite *(Mononychellus tanajoa)*
- The coffee red mite *(Oligonychus coffeae)*
- The cotton red mite *(Oligonychus gossypii)*

Spider mites have been recorded on a wide range of wild and cultivated plants – including beans, cassava, cotton, citrus, okra, tomato, papaya, potato, tobacco, strawberry, various cucurbits and legumes.

First symptoms are usually clusters of yellow spots on the upper surface of leaves, which may also appear chlorotic. This gives the leaf a speckled or mottled appearance. Feeding by spider mites may lead to a change of leaf colour in some plants such as okra, cotton, coffee, tea and some ornamentals. Attacked leaves turn bronze, or rusty, purple or yellow brown colour. Spider mites and webbing are present on the lower leaf surface, which may appear tan or yellow and have a crusty texture.

Feeding by the cassava green mite leads to stunted and deformed cassava leaves. Severe attacks cause the terminal leaves to die and drop and the shoot tip looks like a "candle stick".

Under severe infestations, leaves redden, whither and drop. Some spider mites *(e.g. T. evansi)* produce large amounts of webbing. Heavy infestation will result in a fine cobwebby appearance on the leaves and the whole plant. Plants die when infestation is severe.

3.6.1.3. The damage caused

Affected plant stages

Vegetative growing stage, flowering stage, post-harvest

Affected plant parts

Leaves, inflorescences, fruits

Symptoms by affected plant part

Leaves: Lesions, abnormal colours, abnormal leaf fall, yellowed or dead
Inflorescences: Yellow or abnormal colour, abnormal flower fall, premature fall of young fruits

Generally, spider mites prefer the undersides of leaves, but if the attack is severe, infestation will occur on both leaf surfaces as well as on the stems and fruits. They suck the sap of plant tissues. Infestations are most serious in hot and dry conditions. Because they multiply very quickly, they are able to destroy plants within a short period of time. Spider mites spin silk threads that anchor them and their eggs to the plant. The fine web produced by spider mites protects them from some of their enemies and even from pesticide applications.

The most destructive spider mite species is the tobacco or tomato red spider mite *(Tetranychus evansi)*. This mite is a very serious pest in tomato crops and other members of the Solanaceae family (tomato, potato, eggplant, tobacco and wild plants and weeds like black nightshade, bitter apple and wild gooseberry). This species originates from Brazil, South America and was accidentally introduced into Southern Africa during the 1980's.

Since then this spider mite has slowly made its way north. Presently, it is one of the major constraints in tomato production in Kenya, Mozambique, Malawi, Namibia, Zimbabwe and Zambia. When left uncontrolled, the farmer can lose his or her production within a week.

Two spotted spider mite - Whitney Cranshaw, Colorado State University, Bugwood.org

The two spotted spider mite *(Tetranychus urticae)* and the carmine spider mite *(Tetranychus cinnabarinus)* cause yield loss on tomatoes only in exceptional cases such as; very hot and dry conditions, when its natural enemies are destroyed, and in the presence of other highly infested crops that has an insufficient water supply.

Damage by spider mites on beans is most severe when mite feeding occurs early in the vegetative period.

Another important species is the cassava green mite *(Mononychellus tanajoa)*. This mite is green in colour at a young age, turning yellowish as adult. It was accidentally introduced from South America and its rapid spread has led to it becoming one of the most destructive pests of cassava in Africa.

The cotton red mite *(Oligonychus gossypii)* has spread widely in Africa. It is commonly found on cassava, mainly during the dry season, but has much less economic impact than the cassava green mite. It also attacks cotton, citrus, peach, papaya, beans, okra, peanut and ornamentals.

The coffee red mite *(Oligonychus coffeae)* is found on unshaded coffee and tea crops in localised attacks during the dry season. They attack the upper surface of mature leaves. As a result, the upper surface of fully hardened leaves turn rusty, purple or yellow brown colour. Under drought stress, young leaves may also be attacked.

3.6.1.4. Cultural practices to prevent its occurrence

Inspecting your field regularly is very important because the population build-up of mites is very rapid. At the beginning of the infestation the distribution of mites is very patchy. Control must start early because it is very difficult to control the mite population once they are established. A recommended monitoring method for mites on tomato is to:

> Randomly select 20 tomato plants and assess the level of damage caused by the mites of 3 leaflets/plants by using a damage leaf index ranking from 1 to 5 (1 is few yellow spots, 5 is leaf totally covered with spots and dry patches occur). Once the average damage level exceeds the first rank, control measures should start immediately.

Less experienced farmers sometimes have difficulty with early identification of mites, since the symptoms resemble a nutrient deficiency or plant disease. Close inspection of the underside of affected leaves shows mites as tiny moving specks (red or yellow-greenish depending on the species) and whitish particles (these are skins that have been shed).

Further cultural practices are:

- Position nurseries away from infested crops and avoid planting next to infested fields
- Grow healthy crops; avoid water and nutrient stress. Apply mulch and incorporate organic matter into the soil to improve the water holding capacity and reduce evaporation
- Keep perennial hedges such as pigeon peas. They are said to encourage predatory mites, which predate on spider mites
- Uproot and burn infested plants. This method can be successful during the early stages of infestation when the mites concentrate on only a few plants
- Keep the field free of weeds
- Remove and burn infested crop residues immediately after harvest
- Mites favour dry and hot conditions. Influencing the microclimate by reducing the planting distance is reported to suppress spider mite populations. However, this could also enhance fungal diseases, so care should be taken

- When moving through the crop for weeding, pruning, harvesting or any other field work, always work the infested area last in order to minimise the spread of mites on clothing or farm tools

3.6.1.5. Remedies

Natural enemies

A range of natural enemies attack spider mites. The most important are predatory mites, predatory beetles such as small *staphilinidae (Oligota spp)* and ladybirds, lacewings, predatory thrips, *anthocorid* bugs *(Orius spp)*, mirid bugs and predatory flies such as *cecydomyiid* and hoverflies.

Naturally occurring predators are in most cases capable of controlling infestations of the two-spotted spider mite and the carmine red spider mite, provided natural enemies are not disturbed by the severe use of broad-spectrum pesticides – and if the crop is irrigated properly.

This is not the case for spider mites that have been accidentally introduced from other continents. Thus, few natural enemies are known to feed on the tobacco spider mite in Africa. In contrast, natural enemies keep this mite under control in Brazil, its country of origin. ICIPE has recently conducted experimental releases of a predatory mite *(Phytoseiulus longipes)* introduced from Brazil.

The cassava green mite has been effectively controlled by predatory mites *(mainly Typhlodromalus aripo and T. manihoti)* introduced from South America, the home of the cassava green mite (Yaninek and Hanna, 2003).

Several natural enemies of spider mites are commercially available worldwide. The most common is the predacious mite *Phytoseiulus persimilis*.

According to the RealIPM (Kenia & South Africa) January 2008 newsletter, the horticultural export company Oserian has now been spider mite free for one and a half years after using *Phytoseiulus persimilis* and integrated management, saving large amounts of money on acaricides and harvesting much better quality roses. The same predatory mite is also effective for spider mites on French beans, both in greenhouse and field conditions.

Bio-pesticides

- *Neem*
  Neem products, particularly in oil formulations, give reasonable control over spider mites. Neem does have some systemic effect in plants. Apply it as a spray in the same way as other contact insecticides. Spray thoroughly, targeting the undersides of leaves where spider mites tend to cluster. Commercial Neem products are available.

- *Soap spray*
  Apply on the infested plants thoroughly, including the undersides of the leaves. Spray early in the morning or late afternoon.

- *Precaution*
  Soap spray may injure foliage. Test these sprays on a few leaves before applying to the entire field. It may take 2 days for damage symptoms to appear.

- *Pyrethrum*
  Spray natural commercial pyrethrum extracts to control spider mites very early in the early stages of outbreaks. Take care of beneficial insects, which will also be negatively affected by the pyrethrum application.

Flour preparations

Flour mixed in water is said to be very effective against aphids and spider mites. It should be applied in the morning, taking care to spray underside of leaves. As the heat of the sun increases, the mixture dries and the insects are left encrusted in flour, shrivel and die. The coating of flour falls off the leaves so that their ability to photosynthesise is not essentially affected (Gabriele Stoll, 1988).

Glues

Any water-soluble glue, particularly those obtained from plants, for example glue (starch) obtained by boiling potatoes and cassava in water has been reported to suppress spider mites. Spray a weak solution to suffocate the insects. The strength of mixes varies greatly according to the glue available but the diluted solution should leave a thin skin coating the plant when the solution has dried (H. Elwell et. al, 1995).

Others

The above mentioned and other natural control methods against spider mites are currently being tested in several Eastern and Southern African countries. Currently, the Mashare ADI (Agricultural Development Institute) in the Kavango Region in Namibia is carrying out tests with chilli, garlic and soap extracts and a mixture of buttermilk and flour as remedies. The results are not yet available, however for the latest information; contact the Horticultural Section at Mashare ADI or the Kavango Horticultural Production and Marketing Project *(KHPMproject@mweb.com.na)*.

Botanicals such as neem and *Tephrosia sp.* are currently being evaluated in Malawi, Zimbabwe and Kenya.

Water

Overhead irrigation or hosing with a strong jet of water knocks off mites and destroys their webs. Be sure to spray under the leaves. However, this should be done early in the day to allow the foliage to dry. Wet foliage for an extended period leaves the plant susceptible to fungal diseases.

Apply water to pathways and other dusty areas at regular intervals.

3.6.2. Thrips

3.6.2.1. Scientific and common names

Ceratothripoides brunneus, Diarthrothrips coffeae, Frankliniella schultzei, Frankliniella occidentalis, Haplothrips spp., Heliothrips haemorrhoidales, Hercinothrips bicinctus, Megalurothrips sjostedti, Scirtothrips aurantii, Scirtothrips kenyensis, Thrips tabaci

3.6.2.2. What it is

Thrips attack a wide number of vegetables, fruit and flower crops and cereals. Some species are specific to particular host plants while others feed on many host plants. Both onion thrips and western flower thrips attack a wide variety of plants, including cereals and broadleaved crops.

Eggs are very tiny. A single egg is 0.25mm long and 0.1mm wide. They are white when freshly laid and turn pale yellow toward maturation. Eggs are usually laid singly inside the plant tissue and are therefore not visible. Some thrips *(e.g. Haplothrips spp)* lay eggs singly or in clusters attached to the plant surface.

Larvae: The first and second instar larvae are very small (0.5 to 1.2mm), elongated, slender and vary in colour from pale-yellow, orange or red according to the species. They have piercing-sucking mouthparts. They resemble a miniature version of the adults but do not have wings.

Pre-pupa and pupae: These two or three instars are intermediate forms between the nymph and the adult. They have short wing buds, but no functional wings. During these stages, thrips are inactive and do not feed and therefore they do not cause any damage to the plant. Pupation may occur on a plant or in the soil beneath, depending on species. Adult thrips are small (usually 1 to 1.5mm),

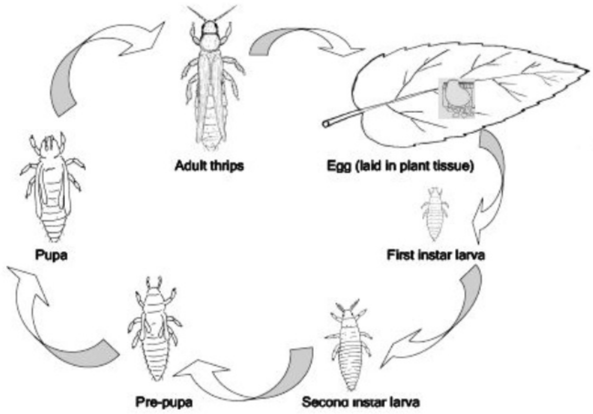
slender and usually winged. The wings are long, narrow and fringed with long hairs and at rest, are tied on the back along the body. Their colour varies according to the species. Most species are black, brown or yellow
The life cycle takes about two to three weeks under warm conditions, which gives them an enormous capacity to multiply. Thrips migrate between different hosts.

3.6.2.3. The damage caused

Thrips on onion

Symptoms
The characteristic symptom of attack is a silvery sheen of the attacked plant tissue and white or silvery patches and streaks on leaves, fruits and pods. Affected tissue will dry up when the damage is severe. A further indicating of attack by thrips is small black spots of faecal material on the infested parts of the plant. However, small dark spots can also be observed on plants attacked by other insects such as lace bugs. Damaged leaves may become papery and distorted. Infested terminals lose their colour, roll and drop leaves prematurely. Feeding on fruits leaves a roughened silvery texture on the skin.

Thrips damage on egg plant



Thrips life cycle

Thrips

Affected plant stages

Flowering stage, post-harvest, seedling stage and vegetative growing stage

Affected plant parts

Growing points, inflorescence and leaves

Symptoms by affected plant part

Growing points: dead heart
Inflorescence: Lesions; abnormal colour; abnormal forms
Leaves: Lesions; abnormal colours; abnormal forms

Thrips feed on the lower surface of leaves, buds, flowers and fruits. Both larvae and adults feed by piercing the plant tissue and sucking up the released plant juices. A heavy infestation causes premature wilting, delay in leaf development and distortion of leaves and young shoots. Under heavy infestations, when buds and flowers are attacked, abortion usually occurs. Thrips attacks may also result in premature fruit shed. Thrips may also cause cosmetic damage to plants. Thrips feeding causes scarring of flowers and skin blemishes and distortion of fruits (scarring, russeting, fruit cracking or splitting), which affects fruit quality. In addition, egg-laying spots may be surrounded by slightly raised, light coloured areas, which may lead to rejection of bananas, tomatoes or peas grown for the export market.

Thrips also cause indirect damage as vectors of disease-causing virus, fungi and bacteria. Several species of thrips are vectors of the tomato spotted wilt virus group in a wide range of crops (bell pepper, lettuce, pea, tobacco, potato, tomato, groundnut and a large number of ornamental plants). In addition, injuries caused by thrips feeding may serve as entry points for bacterial or fungal pathogens. For example, infection by *Fusarium* ear rot on maize is facilitated by western flower thrips and purple blotch in onions by onion thrips.

The stage of growth when an infestation occurs seems to determine the extent of yield loss. Direct feeding damage is most harmful in dry climatic conditions, when heavily attacked plants lose moisture rapidly. Young plants are particularly susceptible and there may be total losses at the seedling stage in onions, cabbages and cotton.

Major species of thrips attacking crops in Africa:

African bean flower thrips *(Megalurothrips sjostedti)*
Coffee thrips *(Diarthrothrips coffeae)*
Blossom or Cotton bud thrips *(Frankliniella schultzei)*
Black tea thrips *(Heliothrips haemorrhoidales)*
Banana thrips *(Hercinothrips bicinctus)*
Citrus thrips *(Scirtothrips aurantii)*
Cacao or red banded thrips *(Selenothrips rubrocinctus)*
Tomato thrips *(Ceratothripoides brunneus)*
Cereal thrips *(Haplothrips spp)*
Tea thrips *(Scirtothrips kenyensis)*
Onion thrips *(Thrips tabaci)*
Western flower thrips *(Frankliniella occidentalis)*

3.6.2.4. Cultural practices to prevent its occurrence

Monitoring and decision-making

Monitor the crop regularly. Early detection of thrips is important to determine an appropriate control strategy. In the case of onions, randomly sample plants and evaluate thrips numbers and damage under leaf folds. Sample at least 5 plants from 4 separate areas of the field. In other crops, pay particular attention to flower buds and flowers. Thrips can be easily detected by shaking leaves and flowers over a white piece of paper.

Adult thrips can be monitored by mass trapping with coloured (blue, yellow or white) sticky traps or water traps in the nursery or field.

The type of crop damage needs to be taken into consideration when deciding on the need for control measures and the appropriate strategy. This is particularly important in the case of thrips-transmitted virus diseases. The prevention of these diseases is difficult since relatively small numbers of vector thrips can result in high rates of pathogen spread. In general, transmission of the plant pathogen occurs so quickly that the thrips are not killed before they have transmitted the virus to the plants. In these cases, the best strategy is to keep the crop free of thrips at least during the most vulnerable period of the crop (i.e. young growth).

Irrigation
Provide good growing conditions for the plants to ensure rapid growth. Environmental stress that weakens plants makes them more susceptible to thrips attack. In particular, plants under water stress are highly susceptible to direct thrips damage. Adequate irrigation is a critical factor in minimising damage.

Tillage
Ploughing, harrowing and solarisation can kill pupae in the soil from previously infested crops.

Planting date
Well-established crops can withstand attack better than those that are newly planted; making early planting desirable particularly in rain-fed crops. This is especially beneficial in light, dry soils, where it is common for plants to suffer from water shortage as the growing season progresses.

Intercropping
In some cases intercropping has been found to reduce thrips infestation. The effects are probably caused through shading of the lower crop by the taller intercrop, which influences the abundance and activity of the thrips. However, thrips reduction is not necessarily translated in yield increase. The effect of intercropping on thrips numbers and damage depends, among other factors, on the selection of plants. In some cases intercropping does increase the numbers of thrips in susceptible crops. Thus, populations of the onion thrips increase on potatoes when intercropped with shallot and garlic, as does *Caliothrips indicus* on groundnuts intercropped with pigeon pea and mung bean. A mixed cropping habitat is likely to encourage thrips predators, as has been shown for the minute pirate bugs *(Orius tristicolor)* (Parella and Lewis, 1997).

In Egypt, intercropping onion and garlic with tomato reduced infestations of the onion thrips by almost 80%, but the yield of both crops declined. In England, infestation of the onion thrips *(Thrips tabaci)* on onions was halved when intercropped with carrots. The effect was greater with closely alternating single rows of each. Infestation of the onion thrips on cabbage was reduced tenfold by growing clovers *(Trifolium repens or T. subterraneum)* between rows (Parella and Lewis, 1997).

In Kenya, populations of the African bean flower thrips *(Megalurothips sjostedti)* and *Hydatothrips adolfifriderici* on cowpea buds were almost halved by intercropping the cowpea with sorghum and maize (Parella and Lewis, 1997).

Crop rotation
Avoiding successive planting of susceptible crops helps reduce the impact of thrips. Identification of the thrips involved is important to know the host range of crops adequate for crop rotation. Thus, in the case of onions, they should not be planted near grain fields.

3.6.2.5. Remedies

Natural enemies

Natural enemies, in particular predators are often found feeding on thrips. They include predatory thrips, predatory mites *(e.g. Amblyseius spp.) anthocorid* bugs or minute pirate bugs *(Orius spp.)*, ground beetles, lacewings, hoverflies and spiders. They are important in the natural control of thrips. The parasitic wasp (*Ceranisus menes)* is an important natural enemy. The farmer can increase the number of these natural enemies by providing protective habitats for them.

Pathogens such as the fungi *Entomophthora, Verticillium lecanii, Beauveria bassiana and Metarhizium anisopliae* are also important in the natural control of thrips. Spray formulations of *Beauveria bassiana* are used for the control of thrips. This microorganism is most effective when used early on, before large thrips populations have built up.

The natural enemies *Beauveria bassiana, Orius jeanneli and Amblyseius californicus* are commercially available.

Bio-pesticides

A bio-pesticide, derived from the fermentation of an Actinomyces bacterium, commonly found in the soil is effective.

Neem

Neem-based pesticides are reported to control young nymphs, inhibit the growth and development of older nymphs and reduce egg-laying by adult thrips. Adding 0.1% to 0.5% of soft soap enhances the efficacy of neem-based pesticides.

Other botanical pesticides that have been recommended for management of thrips include garlic, rotenone, ryania, pyrethrum and sabadilla. A homemade botanical spray of garlic and pepper has been recommended for organic growers in the USA (ATTRA, 2004). The garlic/pepper mixture is made by liquifying two bulbs of garlic and two cayenne or habanero (hot) peppers in a blender filled with a ⅓ of water. Solids are strained and enough water is added to make 4 litres of concentrate. The spray solution is prepared by mixing ¼ cup of the concentrate with 2 tablespoons of vegetable oil and enough water to make 4 litres for application (ATTRA, 2004).

Sulphur, insecticidal soaps and diatomaceous earth have demonstrated efficacy in suppressing thrips in several crops. Three applications of superfine sulphur at monthly intervals are recommended in fruit crops. Lime sulphur has also been recommended as an alternative. However, care should be taken when using sulphur as it has been reported to harm some predatory mites.

Flour/starch preparations have been recommended for control of thrips.
See flour preparations on page 57.

Coloured sticky traps (blue, yellow or white) or water traps are useful for monitoring and in some cases reducing thrips by mass trapping them in the nursery or in the field. Research in California has shown that hot-pink sticky cards attract more thrips than blue-coloured traps. The colour spectrum of the boards is important for the efficacy of the sticky traps. Bright colours attract more thrips than darker ones.

Overhead irrigation and rainfall reduce thrips numbers. Irrigation by flooding fields has been found to reduce thrips damage. It destroys a large proportion of pupae in the soil.

Ultraviolet-absorbing plastics, used to build walk-in field tunnels have proved effective in protecting crops from western flower thrips.

3.6.3. White flies

3.6.3.1. Scientific and common names

Aleurodicus disperses, Aleurothrixus floccosus, Aleyrodes proletella, Bemisia tabaci, Trialeurodes vaporariorum

3.6.3.2. What it is

The tobacco whitefly *(Bemisia tabaci)* and the greenhouse whitefly *(Trialeurodes vaporariorum)* attack a very wide range of wild and cultivated plants. *Bemisia tabaci* is the dominating whitefly in the region. Its host range includes cotton, tobacco, vegetables (tomatoes, eggplant, okra, bell peppers, cucurbits, etc.), legumes (beans, soybeans, cowpeas and groundnut), tuber and root crops (sweet potato, cassava, potato) among others. The host range of *Trialeurodes vaporariourm* is similar to the one for *Bemisia tabaci*, but the former usually occurs at higher altitudes and cooler climates than *B.tabaci*. *Trialeurodes vaporariorum* attacks many plants grown under protected conditions (greenhouses) in temperate countries, the most severely affected crops are aubergine, cucumber, beans, sweet peppers, tomatoes and a large number of ornamentals. The status of this whitefly in field grown crops in the region is not clear.

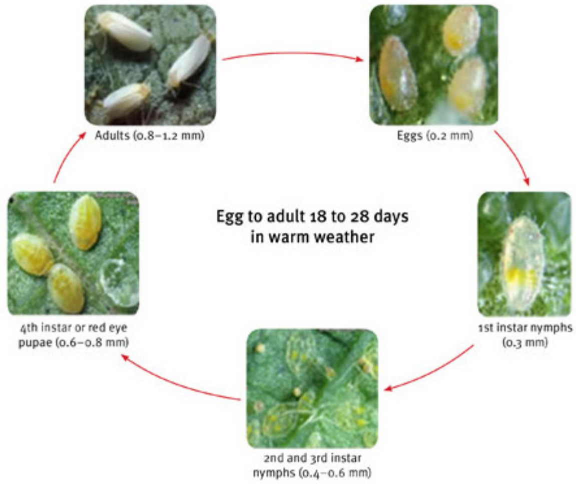
The cabbage whitefly *(Aleyrodes proletella)* is a pest of Brassicas but rarely reaches levels that require intervention.

The citrus woolly whitefly *(Aleurothrixus floccosus)* is found mainly on citrus plants, but also attacks coffee (arabica), guava, eggplant, aubergine, mango and several wild plants. The spiralling whitefly (Aleurodicus dispersus) feeds on many plants. In West Africa, it has been observed causing damage to many food crops, including cassava, soybean, pigeon pea, citrus, papaya and others. This whitefly has also been recently found in East Africa. Eggs are tiny (about 0.2mm long) and pear-shaped. They stand upright on leaves, being anchored at the broad end by a short stalk inserted into the leaf. They are usually laid in arcs or circles, on the undersides of young leaves. Eggs are whitish in colour when first laid, but gradually turn brown. Some whiteflies deposit large quantities of wax around the eggs in the form of a loose spiral like a fingerprint. Hatching occurs after 5 to 10 days at 30°C depending on species, temperature and humidity.

At hatching, the first instar or crawler is flat, oval, very small (barely visible, even with a hand lens) and greenish-white in colour. It is the only mobile immature stage. It moves to a suitable feeding location on the lower leaf surface where it settles. It moults, losing its legs and antennae and cannot move throughout the remaining immature stages. They pass through two additional feeding stages, known as nymphs. The nymphs are usually oval or oval-elongate in shape and are simple in appearance like small scale insects. Nymphs of many species produce waxy secretions around the margins and the dorsal surface of their body.

The last (fourth) immature stage is known as puparium. In this stage, the metamorphosis into an adult occurs. The red eyes of the adult developing inside are visible through the skin (integument). As the other larval instars, it is greenish in colour and scale-like, but becomes more bulky shortly before the adult emerges. They are usually found on mature leaves. The adult emerges about 6 days after pupation. It usually emerges through a T-shaped split in the dorsal surface of the pupal case.

The total nymphal (immature) period lasts for 2 to 4 weeks depending on temperature. Large populations may develop within 3 weeks under optimum conditions and the lower leaf surfaces may be almost covered by immature stages.



SLW-lifecycle - www.daff.qld.gov.au

White flies on cabbage

White flies

Adults are small (1 to 3 mm long), with two pairs of wings that are held roof-like over the body. They resemble very small moths. Their body is pale yellow. The body and wings are covered with a powdery, waxy coating. Whiteflies are mostly white, but can also be yellowish and some species have dark or mottled wings. They have sucking mouthparts and are often found clustered in groups on the underside of young leaves and readily fly away when disturbed. A female may live for 60 days; but the lifespan of the male is generally much shorter (9 to 17 days).

Whitefly adults do not fly very efficiently, but once airborne can be transported long distances by the wind. During all stages of the pest's mobility, particularly at the immature stages (when they are small and easily overlooked) they are more likely to be carried on plant materials.

3.6.3.3. The damage caused

Whiteflies cause direct damage to plants by sucking plant sap and removing plant nutrients and weakening them. Damage may be more severe when plants are under water stress. In addition, they often produce large quantities of honeydew that leads to the growth of sooty mould on the lower leaves, blocking or reducing the photosynthetic capacity of the plants. The honeydew also contaminates the marketable part of the plant, reducing its market value or making it outright unsalable. Infested plants may wilt; turn yellow in colour, become stunted or die when whitefly infestations are severe or of long duration.

Whiteflies are also serious indirect pests as vectors of virus diseases. *Bemisia tabaci* transmits serious virus diseases on cassava, cotton, tobacco, tomato, beans, chillies and sweet potatoes. Whitefly transmitted viruses are among the most serious virus diseases on plants; Virus infection often results in total crop losses. This whitefly is the vector of a range of leaf curl disease-inducing viruses, in Eastern and Southern Africa, including Tomato Yellow Leaf Curl Virus, the African Cassava Mosaic Virus, Cowpea Mild Mottle Virus, Watermelon Chlorotic Stunt Virus among others. The African Cassava Mosaic Virus is one of the most significant factors that limit cassava production in Africa.

In sweet potatoes *B. tabaci* transmits the Sweet Potato Chlorotic Stunt Virus, which together with the aphid-transmitted Sweet Potato Feathery Mottle Virus, causes the Sweet Potato Virus Disease, the disease that constrains sweet potato production most in Sub-Saharan Africa (Legg et al., 2003).

Major species of whiteflies in Africa:

The greenhouse whitefly *(Trialeurodes vaporariorum)*
The tobacco whitefly or sweet potato whitefly *(Bemisia tabaci)*
The spiralling whitefly *(Aleurodicus dispersus)*
The citrus woolly whitefly *(Aleurothrixus floccosus)*
The cabbage whitefly *(Aleyrodes proletella)*
Presence of whiteflies can also be recognised by a cloud of tiny whiteflies swarming when the plants are shaken. The whiteflies will soon resettle on the plants

Affected plant stages

Seedling, vegetative growing and flowering stage

Affected plant parts

Leaves
Symptoms by affected plant part
Leaves: Honeydew or sooty mould

3.6.3.4. Cultural practices to prevent its occurrence

Monitoring and decision making

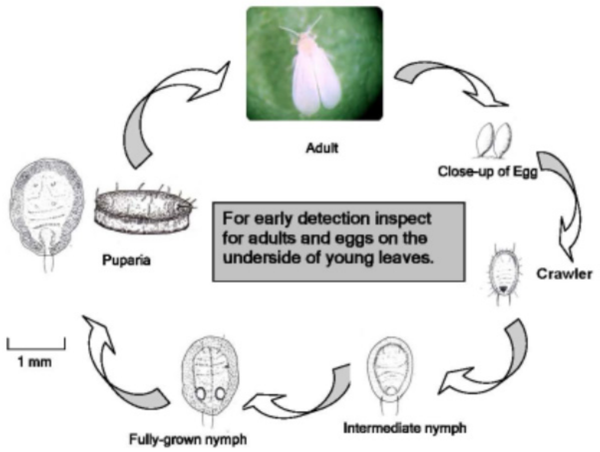
For early detection, inspect for adults and eggs. They are usually found on young leaves. Watch out for whiteflies swarming when the crop is disturbed. It is important to identify the whitefly and the type of damage caused, as well as the stage of the crop for decision making. Small numbers of whiteflies do not cause major direct plant damage to healthy, mature plants and therefore do not justify any chemical intervention. Control measures can be justified if large numbers of whiteflies are present during the early stages of the crop. However, where virus transmission is involved, as is the case of the tobacco whitefly on tomatoes, sweet potato or cassava, even small numbers of whiteflies may need to be controlled.

Yellow sticky traps can be used to monitor the presence of whiteflies for timing of interventions. *See more on traps on page 67.*

The following description helps to distinguish the most important whitefly species in Africa:

Adults of the tobacco whitefly *(B. tabaci)* have wings all white in colour and hold them tent-like over the body, giving a narrow, triangular, appearance while other whiteflies usually hold their wings flatter, which give them a flattened appearance.

The larval stages and puparium of this whitefly are naked (not covered with waxy white material). They appear as pale yellow oval specks to the naked eye. On closer inspection, they are oval and flat with a rounded outside margin, tapering toward the leaf surface as viewed from the side. In contrast, the pupae of the greenhouse whitefly have distinctly ridged outside margins with flat, vertical surfaces surrounded by short threads.



White fly life cycle

Adults of the citrus woolly whitefly *(Aleurothrixus floccosus)* have wings all white in colour. Eggs are in a circle or half circle. The immature stages are covered by abundant, dirty-looking, flocculent white wax, which gives them a woolly appearance. They usually form large dense colonies covered with cotton-like secretions on the lower leaf surface.

Adult spiralling whiteflies *(Aleurodicus dispersus)* are white, although pale or dark spots may occasionally occur on the forewings. Eggs are laid on the lower leaf surface in characteristic spiral patterns, resembling fingerprints of white material secreted by the female. Nymphs and adults produce a considerable amount of white wax. When the adults move around, they leave behind a trace of waxy material. They usually form dense colonies on the lower leaf surfaces.

Providing conditions for growing healthy plants

Ensure adequate growing conditions for the crop such as good soils, adequate water supply, proper feeding (avoid application of high doses of nitrogen fertiliser, since it favours development of the pest), proper spacing and good nursery management to start the crops with healthy, vigorous plants. If the plants are to be raised in a seedbed and later transplanted like many vegetables, keep the seedlings protected under a fine meshed insect netting until they are ready for transplanting. Make sure the netting is always properly closed.

Mixed cropping systems

Selection of crops for intercropping can be used to manage whitefly populations. For instance, interplanting tomatoes with capsicum or cucumber has reduced whitefly numbers when compared with tomato crops on their own or tomatoes planted with eggplant or okra.

The planting of border rows with coriander and fenugreek, which are a non-host of *B. tabaci*, will serve as windbreaks and are favourable for natural enemies and also repellent to whiteflies.

Growing African marigolds and nasturtiums has been reported to discourage whiteflies. Growing *Nicandra physalodes* (Apple of Peru of Shoo-fly plant) in between crops deters whiteflies, especially in greenhouses.

Planting date

Avoid the season when whiteflies are more likely to occur.

Host plant resistance

Growing resistant varieties is particularly useful for the management of diseases caused by viruses transmitted by whiteflies, in particular, *B. tabaci*. Outbreaks of African Cassava Mosaic Virus (ACMV) in East Africa are associated with the varieties grown and are less devastating in areas where many different varieties are grown. The outbreak of ACMV in East Africa has been contained by farmers adopting resistant varieties introduced from Nigeria's International Institute of Tropical Agriculture (IITA) or those selected by the National Agricultural Research Organisations from the available local varieties. Resistant varieties introduced from Nigeria include "SSA"," Nase 1", "Nase 2" and "Nase 3" (Migyera) (OFDA-CMD Project).

Tomato varieties resistant to TYLC virus are also available.

Sanitation

Weeds play an important role in harbouring whiteflies between crop plantings. They also often harbour whitefly-transmitted viruses. Therefore, weeds should be removed in advance of planting. Fields should also be kept weed free.

3.6.3.5. Remedies

Natural enemies

Whiteflies are attacked by a large number of natural enemies: parasitic wasps *(e.g. Eretmocerus spp., Encarsia spp.)*, predatory mites *(Amblyseius spp.* and *Typhlodromus spp.)*, predatory thrips, lacewings, rove beetles and ladybirds. The dusty lacewing (*Conwentzia africana)* is considered to be one of the most important predators of *B. tabaci* in East and Southern Africa (Legg, 2003).

Parasitised pupae can be recognised by the black colour of the puparium and later, when the parasitic wasp has emerged, by an irregular round hole on the puparium, which is chewed by the emerging wasp. Parasitic wasps are very important for the control of whiteflies. *Encarsia formosa* in particular, has been widely used for the control of whiteflies worldwide.

Two parasitic wasps *Encarsia guadaloupe* and *Encarsia haitiensis* an introduced pest in West Africa, have provided control of the spiralling whitefly, (Neuenschwander, 1998; James *et al*, 2000).

The citrus woolly whitefly, accidentally introduced into East Africa, is now under control by the parasitic wasp *Cales noacki*, introduced and released in the region in the late 1990s.

Several fungi *(e.g. Verticillium lecanii, Beauveria bassiana, Paecilomyces fumosoroseus)* attack whiteflies and can be useful control agents in situations where the crop is grown in high humidity conditions. Commercial preparations are available.

Mortality of whiteflies by natural enemies is particularly important in crops where feeding damage is the cause of losses, rather than virus transmission. In cases where the whiteflies are vectors of virus diseases, control provided by natural enemies is generally not sufficient to prevent virus spread and transmission.

Bio-pesticides

Neem (Azadirachta indica)

Neem-based pesticides are reported to control young nymphs, inhibit growth and development of older nymphs and reduce egg laying by adult whiteflies. They also significantly reduce the risk of Tomato Yellow Leaf Curl Virus transmission. Efficacy of neem-based pesticides can be enhanced by adding 0.1% to 0.5% of soft soap.

Physical methods

- *Traps*

  Yellow sticky traps usually used to monitor the presence of whiteflies for timing of interventions, have also been used as a control method for low density infestations in enclosed environments.

  Yellow plastic gallon containers mounted upside down on sticks coated with transparent automobile grease or used motor oil. These should be placed in and around the field at about 10 cm above the foliage. Clean and re-oil when traps are covered with flies.

  Yellow sticky boards. To use, place 1 to 4 yellow sticky cards per 300 m^2 of field area. Replace traps at least once a week. It is difficult to determine the population of newly trapped whiteflies on a sticky card from the previously trapped ones. To make your own sticky trap, spread petroleum jelly or used motor oil on yellow painted plywood, 6 x 15cm in size. Place traps near the plants but faraway enough to prevent the leaves from sticking to the board. When hung, traps should be positioned 60 to 70cm above the plants.

  Yellow plastic trapping sheets. A 2m long x 75cm wide yellow plastic sheet coated with motor oil with each end attached to bamboo or wooden poles and carried by 2 people through the field to mass capture adult flies. Yellow plastic drinking cups can be coated with adhesives and stapled on stakes above plant canopies to trap flies.

- *Flour/Starch preparation*
  Flour/Starch preparation has been listed by several authors as successful against whiteflies. Ensure the spray reaches the underside of the leaves, where the whiteflies like to hide.

- *Plastic covers and mulches*
  Plastic covers and mulches. Preventing physical contact between the whiteflies and the plant can prevent the transmission of virus diseases. This can be done by using plastic covers and mulches and by cultural methods. Several cover crops (forage, peanut, weeds) and inert covers (silver, yellow and white/black plastic mulches) have been shown to reduce whitefly damage in tomatoes. However, when using plastic covers, care should be taken to avoid sun-scald. This is effective as long as the plants are young and do not cover the mulch. The whiteflies will be more attracted by the colour of the plastic mulch. The heat of the plastic kills the whiteflies. The protection can last for 10 to 20 days after transplanting and about 30 days after direct seeding.

  Covering tomato seedling nurseries with nylon nets or the use of tunnels for 3 to 5 weeks protects seedlings from whiteflies infestation. These methods have been reported to reduce the transmission of the TYLCV in several countries.

  Spraying with soap and water reportedly controls whiteflies. However, care should be taken, since the use of strong soaps, or soft soaps at high concentrations can scorch the plants.

3.6.4. Fruit fly

3.6.4.1. Scientific and common names

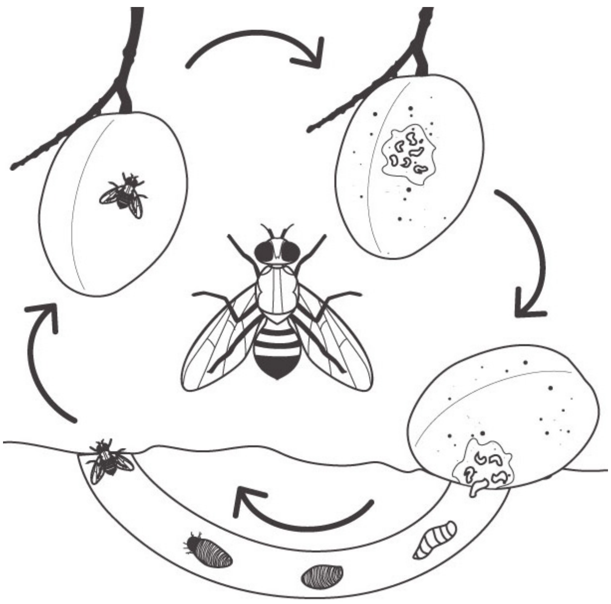
Ceratitis spp., Dacus spp., Bactrocera spp.

3.6.4.2. What it is

The morphology of the various fruit fly species is similar.

Eggs of fruits flies are small, white and slender. They are laid under the skin of fruits in groups of 3 to 8 eggs, depending on the species. The flies lay eggs on mature green and ripening fruit. Some species may lay eggs in unripe fruitlets. Eggs hatch within 1 to 2 days.

The larvae are whitish maggots. They feed on the fruit flesh causing the fruit to rot. After 4 to 17 days the maggots leave the fruit, making holes in the skin and drop to pupate in the soil. The pupae are white, brown or black and 4mm to 12mm long. They are found in the soil between 2cm and 5cm beneath the host plant. The flies emerge from the pupae 10 to 20 days after pupation depending on climatic conditions.



Life cycle fruit fly -preventfruitfly.com.au

Fruit fly

Adult fruit flies are 4mm to 7mm long, brightly coloured, usually in brown-yellow patterns. The wings are spotted or banded with yellow and brown margins.

Fruit flies attack a wide variety of soft, fleshy fruit and vegetable crops.

The Mediterranean fruit fly *Ceratitis capitata* feeds and causes damage to a very wide range of crops.

Major host plants of *Ceratitis cosyra* include mango, guava, sour orange, marula, wild custard apple and wild apricot.

Ceratitisrosa is recorded from over 100 plant species. In Africa, it attacks mango, papaya, guava and custard apple. It is also a common pest of arabica coffee in eastern Africa.

Ceratitis fasciventris is a major pest of mango, guava and coffee in eastern and western Africa.

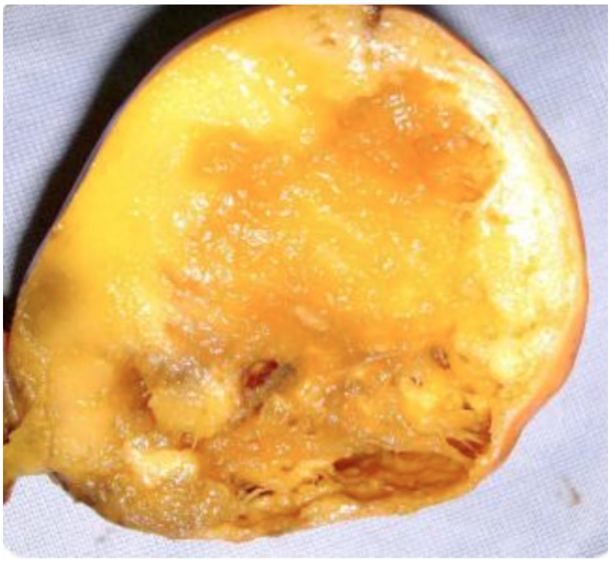
Bactrocera invadens, a new species recently introduced into East Africa, attacks primarily mango, although it has been reared from several other plants (e.g. tomato, banana, guava, marula, avocado).

Bactrocera cucurbitae, Dacus bivitattus, D. ciliatus and D. frontalis are pests mainly of cucurbit crops.

3.6.4.3. The damage caused

Fruit flies cause direct damage to fruit by puncturing the skin to lay eggs. During egg laying, bacteria from the intestinal flora of the fly are introduced into the fruit. These bacteria cause rotting of the tissues surrounding the egg. When the eggs hatch, the maggots feed on the fruit flesh making corridors which provide entry points for pathogens and increase the fruit decay, making them unsuitable for human consumption.

Fruit fly on chilli



Fruit fly damage in mango

Fruit fly damage on marrow

Generally the fruit falls to the ground as, or just before the maggots pupate. In fruits for export, fruit flies cause indirect losses resulting from quarantine restrictions that are imposed by importing countries to prevent the entry of fruit flies. Nearly all fruit fly species are quarantine pests.

Major species of fruit flies attacking crops in Africa:

African invader fly *(Bactrocera invadens)*
Melon fly *(Bactrocera cucurbitae)*
Pumpkin fly *(Dacus bivittatus)*
Jointed pumpkin fly *(Dacus vertebratus)*
Mediterranean fruit fly or medfly *(Ceratitis capitata)*
Natal fruit fly *(Ceratitis rosa)*
Mango fruit fly or Marula fruit fly *(Ceratitis cosyra)*

Affected plant stages:

Fruiting stage

Affected plant parts:

Fruits / Pods

Symptoms by affected plant part:

Fruits / Pods: Internal feeding; lesions; abnormal exudates; visible mould; discolouration; odour

3.6.4.4. Cultural practices to prevent its occurrence

Orchard sanitation

Poorly managed or abandoned orchards can result in buildup of fruit fly populations. Remove fruits with dimples and oozing clear sap. This method, although laborious, is more effective than picking rotten fruits from the ground, as the maggots may have left the fruits to pupate. To be effective, this has to be done regularly (twice a week for the entire season). Kill the maggots by burning, burying or tying collected fruits in black plastic bags and exposing them to the heat of the sun for a few hours to kill the maggots. Alternatively, feed fruits to pigs or poultry. When burying fruits, ensure that the fruits are buried at least 50cm (about two feet) deep to prevent emerging adult flies from reaching the soil surface.

Early harvesting

Harvesting crops early when they are still green helps protect some crops from fruit fly damage. Fruit flies cannot develop in certain fruits such as papaya, banana and sapodilla when they are green. Only ripe fruits are good hosts. However, in other crops, such as mango this practice is not effective as some fruit fly species like *Bactrocera invadens* and *Ceratitis cosyra* are capable of infesting even immature or green mangoes.

3.6.4.5. Remedies

Biological pest control

Natural enemies

Several natural enemies can contribute to the suppression of fruit flies. Major natural enemies are parasitic wasps and predators such as rove beetles, weaver ants, spiders, birds and bats. In particular, weaver ants have been shown to be very efficient in protecting fruit trees from pests, including fruit flies. These ants prey on fruit flies, but most importantly, their presence and foraging activity hinders the fruit flies from laying eggs, resulting in reduced fruit fly damage, as shown in mango orchards in Benin (Van Mele *et al.*, 2007).

Although natural enemies alone do not give satisfactory control of fruit flies, efforts should be made to protect them and to complement their effect on fruit flies with other management options.

Free range chickens in orchards do considerable damage to fruit fly populations, as they scratch out the larvae hibernating under the trees.

Tiny wasps *(e.g. Bracon spp.)* parasitise the maggots of fruit fly. Eggs and larvae of these parasitoids are found inside the bodies of the maggots. The parasitoid larvae are tiny, cream-coloured grubs that feed in or on other insects. Adult wasps feed on nectar, honeydew or pollen before laying eggs. Dill, parsley, yarrow, zinnia, clover, alfalfa, parsley, cosmos, sunflower and marigold are flowering crops that attract the native *Braconid* populations and provide good habitats for them.

Bio-pesticides and physical methods

Pyrethrum

To control fruit flies, a spray with a pyrethrum solution can be used. It will kill bees if they are sprayed directly, but it does not leave poisonous residues. The best time to use it is in the evenings (after 6pm), when most of the bees are back in their hives.

There is a product commercially available called Flower-DS® (available at the Hygrotech Company). This product is made of natural pyrethrum and is acceptable in organic certified systems.

Precautions: Be careful and spray late in the evening. Follow the spraying instructions. Wear masks and skin protection. All insect poisons are also poisonous to humans even if coming from natural sources.

Frequency of spraying: Start shortly after the beginning of flowering and repeat approx. every 5 days or according to counts.

Please check the insect trap information to count your fly population. If no flies are trapped – there is no need to spray

Neem

Frequent applications of neem can keep fruit fly attack to a minimum.

EM5

A fermentation of EM (Effective Microorganisms), vinegar and alcohol sprayed on the fruit, creates a distasteful barrier and prevents the fruit form being stung by the fruit flies.

For more information see chapter 5. Common control methods for pests & diseases.

Fruit fly trap (Lynfield or bucket trap)

The Lynfield trap is cheap and easy to make. It is made of a cylindrical plastic container with 4 holes evenly spaced on its sides, a lid, a wire hanger and a bait basket (if it is to be used with a dry attractant). Similar traps can be made locally using plastic cool drink bottles.

They can be used with either specific attractants such as methyl eugenol or food baits such as protein hydrolysates or yeast or a piece of fruit (banana, mango). Vinegar is also a very good attractant. Methyl eugenol attracts males of Bactrocera species and of a few Dacus species. Food baits attract both males and female fruit flies, they are not species specific and also attract other insects, including natural enemies.

An alternative food bait that attracts a whole range of fruit fly species in the orchard is waste brewers' yeast at a rate of 45ml per liter water. Use about 250ml of the mixture in each trap. Add one tablespoonful of borax (di-sodium tetraborate) to each trap to prevent rotting of the flies caught.

A simple fruit fly trap is made as follows:

Take a plastic bottle
As bait, use ½ cup vinegar, mix with water
Add 4 to 6 drops liquid dish soap (it heavies down the wings and the fruit flies drown). Do not stir
Take a pen or pencil and poke 4 to 5 holes of about 7mm in diameter in the plastic, just big enough for a fruit fly to fit through. Once a fruit fly crawls in, it cannot get out. You would think they would just fly back out through the holes, but they will not! If you see fruit flies crawling around on the surface of your plastic container but not going inside, make the holes larger
Hang the bottle in an area where you have seen the most fruit flies. Depending on the amount of fruit flies you have, you can expect to start seeing the bottle fill up within just a few hours

Fruit fly trap

The trap is filled with bait and hung on the tree about 2cm to 4m above the ground within the canopy layer, in a semi-shaded spot, preferably in the upwind part of the canopy. The trap should be hung in such a manner that branches and leaves are nearby, but not touch the trap. Traps should be hung 10cm to 50m apart, depending on the bait used. Collect catches weekly and sieve them.

Fruit bagging

Bagging prevents fruit flies from laying eggs on the fruits. In addition, the bag provides physical protection from mechanical injuries (scars and scratches). Although laborious, it is cheap, safe and gives a more reliable estimate of the projected harvest. Bagging not only protects fruit from fruit fly damage, it also protects the fruit from physical damage and improves their market appearance. However, it is only practical to use on small trees.

How to make a bag

Cut old newspapers measuring 15cm x 22cm or 12.5cm x 27.5cm for mango and for fruits of similar size. Double the layers, as single layers break apart easily. Fold and sew or staple the sides and bottom of the sheets to make a rectangular bag

How to bag a fruit

Blow in the bag to inflate it. Remove some of the fruits, leaving one on each cluster. Insert one fruit per bag then close the bag by firmly tying the top end of the bag with string or wire. Push the bottom of the bag upwards to prevent fruit from touching the bag. Use a ladder to reach as many fruits as possible. Secure the ladder firmly on the ground and for bigger and higher fruits trees, secure or tie the ladder firmly on big branches.

Reminders

Bagging works well with melon, bitter gourd, mango, guava, star fruit and banana. Whole banana bunches may be bagged inside banana leaves. Start bagging the mango fruit 55 to 60 days from flower bloom or when the fruits are about the size of a chicken egg.

When using plastic bags, open the bottom or cut a few small holes to allow moisture to dry up. Moisture trapped in the plastic bags damages and/or promotes fungal and bacterial growth that can cause diseases. Plastic also overheats the fruit. Bags made of dried plant leaves are good alternatives to plastic.

Remove the bags during harvest and dispose of them properly.

3.6.5. Lepidoptera

3.6.5.1 Scientific and common names

Lepidoptera: Noctuidae
African bollworm, Fruitworm, Podborer, Corn earworm, Tomato grub, Tobacco budworm

3.6.5.2. What it is

The African bollworm is a pest of major significance in most areas where it occurs. It damages a wide variety of food, fibre, oilseed, fodder and horticultural crops. It is a major pest due to its high mobility, its ability to feed on many species of plants, its high fecundity and reproductive rate and its capacity to develop resistance to pesticides. The habit of feeding inside the fruiting parts of the plant during most of its development makes bollworms less vulnerable to insecticides. Pesticides should be applied before the caterpillars bore into the fruits/pods. The African bollworm has a strong ability to develop resistance to insecticides. Currently there is a widespread occurrence of resistance in bollworms to popular synthetic pyrethroids in Africa and elsewhere.

African Bollworm on french beans

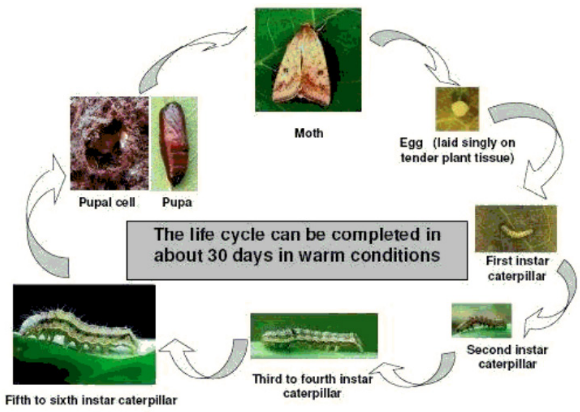
The eggs of the African bollworm are tiny (about 0.5mm in diameter), round and yellowish-white in colour. They darken before hatching. They are deposited singly on tender parts of the plant. Egg-laying generally coincides with early flowering of host crops. Young caterpillars (larvae) are generally yellowish-white to reddish brown. They have a dark brown to black head and several rows of black bumps with short hairs along their backs, which give them a spotted appearance. Fully-grown caterpillars are 35mm to 40mm long. Older caterpillars vary in colour from almost black, brown or green to pale yellow with dark grey yellow stripes along the sides of the body. However, all caterpillars have a typical light stripe along each side of the body. The head is brown or green and mottled. The fully-grown caterpillars drop from the plant and burrow into the soil to pupate. The pupa is shiny brown, about 16mm long, with smooth surface, with two short parallel spines at the posterior tip of the body. Pupation takes place in the soil.

African Bollworm caterpillar

The adult moth is fleshy, yellowish-brown with a dark speck, greyish irregular lines and a black kidney-shaped mark on the forewings. The hind-wings are whitish with a black patch along the outer margin. The moth is about 14mm to 18mm long with a wingspan of 35mm to 40mm. They are relatively strong fliers, dispersing widely within areas where the host plants are found. They can also be carried by strong winds. Moths are strongly attracted to plants that provide honeydew or nectar.

African Bollworm moth

Moths lay a large number of eggs and the life cycle may be completed in a short time under warm conditions. Eggs hatch in 3 to 5 days. Larval and pupal periods last 17 to 35 and 17 to 20 days, respectively. The life cycle is completed in 25 to 60 days depending on temperature.



African Bollworm life cycle

The African bollworm has been reported on 35 crops and 25 wild host plants in eastern and southern Africa (Greathead and Girling 1989). The severity of the damage varies between crops, regions and locations and between seasons. In eastern Africa attacked crops include cotton, French beans, dry beans, okra, peas, legumes, maize, sorghum, sunflower, tobacco and tomato.

Among these crops, the African bollworm is considered a key pest of cotton, chickpea, pigeon pea and tomato (Sithanantham *et al*., 2002). In South Africa crops attacked include peas, beans, wheat, cotton, maize, grain sorghum, oats, barley, sunflower, tobacco, citrus, cucurbits, potato, tomato, lucerne, sunnhemp, cape gooseberry, chickpea and groundnuts (Cherry *et al*., 2003). *Amaranthus spp., Cleome spp.* and *Acalypha spp.* are important wild host plants in Africa.

3.6.5.3. The damage caused

Symptoms:

Larvae feed on leaves, flower buds, flowers, grains and bore into pods and fruits. Excrements (faeces/waste) of the feeding caterpillars are evident on damaged plant parts

Affected plant stages:

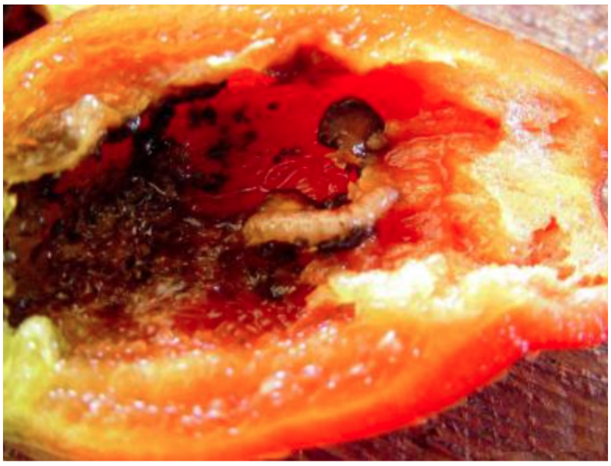
Vegetative growing stage, flowering stage and fruiting stage

Affected plant parts:

Leaves, growing points, inflorescence and fruits/pods

The severity of the damage varies between crops, regions and locations and between seasons.

Caterpillars of the African bollworm feed on leaves, buds, growing points, flowers and fruit. Leaf damage reduces leaf area, which can slow plant growth. Feeding on flowers and fruit causes the main damage. Flower feeding can prevent fruit formation. Caterpillars usually bore clean, circular holes through fruits/pods.



African Bollworm damage in chilli fruit

Excrements (faeces/waste) of the feeding caterpillars are placed away from damaged plant parts.

The holes serve as entry points for secondary infection by diseases causing fruit decay. One caterpillar can damage several fruits/pods. Once they burrow into the fruits/pods they are difficult to reach and to control with insecticides. Often caterpillars feed with the head and forepart of the body inside the fruit/pod and the rest of the body outside.

Moreover, its preference for the harvestable flowering parts of high-value crops including cotton, tomato, sweet corn and cut-flowers makes it responsible for huge economic losses and socio-economic costs.

Crop losses at farm level in Kenya have been estimated at over 50% on cotton and pigeon pea, over 20% on sorghum and millet and over 2 million stems on cut flowers (Kibata, 2002).

In addition, the African bollworm is a quarantine pest. This is important for export crops. If a caterpillar of this pest is detected in a consignment of an export commodity such as flowers and vegetables shipped to Europe, the whole consignment is rejected.

3.6.5.4 Cultural practices to prevent its occurrence

Monitoring and Decision Making

Look out for eggs and small caterpillars. Early detection of eggs or young caterpillars before they bore into the fruits or pods is very important. Once the caterpillars have entered the fruit/pod they are difficult to control and by then they have caused damage. Early detection can be achieved by regular scouting of the crop. Monitoring moth population by using pheromone traps reduces crop inspection time considerably and leads to timely intervention.

Check also for natural enemies. Parasitised eggs are easy to recognise. Healthy eggs are whitish yellow in colour and they turn black when parasitised.

Action thresholds have been developed for high value crops (e.g. tomato, cotton, pulses and tobacco). In these crops the tolerance for insect damage is low and therefore, economic damage thresholds are low.

The following thresholds are given as examples:

Cotton: In Malawi and Zimbabwe, thresholds based on egg numbers have been used successfully in cotton since 1961. Spraying was recommended at an average of one egg per two plants in twice-weekly counts. In the Sudan Gezira, over two eggs or caterpillar per 18 plants and in Australia two eggs per metre of row were used as thresholds (CABI, 2004). It has been argued that control thresholds based on damage are easier to use and more economical than those based on pest density. In the case of cotton, damaged buds are easier to detect and sample than either eggs or small caterpillars. Studies in Tanzania indicate that spraying at damage threshold of 10% to 20% would give adequate protection to the crop. Further fine-tuning of damage thresholds should be concentrated during the first four weeks of flowering when most of the damage by this pest occurs. (Kabissa, 1989).

Tomato: It has been recommended to randomly select 30 tomato plants and examine the leaves immediately below the topmost open flowers to look for eggs of African bollworm (AVRDC, 2000).

The decision to make an intervention to manage this pest should be based on an analysis of the situation (stage of the crop, presence of natural enemies and economic return – based on market value of the crop and the value of the intervention).

Sanitation (Clean cultivation)

Remove and destroy plant residues immediately after harvesting.

Plough the soil after harvesting. This exposes pupae, which may then be killed by natural enemies or through desiccation by the sun.

Mechanical control

Handpick and destroy eggs and small caterpillars. This is feasible in small plots or when infestations are low. For instance, it has been reported that in Ethiopia when pest damage in sorghum is minor, farmers shake the plant to induce the caterpillar to drop from the sorghum head and pick them by hand (Negash and Abate, 2002). It is very important to detect small caterpillars before they enter the fruits.

If African bollworms are detected in the field, sort out the harvested crop very thoroughly and remove the caterpillars manually. This is particularly important for export crops to minimise/avoid rejection by the importing country.

Habitat management

Intercropping and trap crops

Moths of the African bollworm prefer

to lay eggs on certain crops (e.g. pigeon pea, chick pea, crotalaria, maize, tobacco, African marigold, sorghum and sunflower), especially during the flowering period. These crops may be utilised to distract moths from crops that are more vulnerable to African bollworm damage. If trap crops are planted in strips or around the field, the moths will lay eggs on them instead of the main crop. A careful choice of the trap crops and planting dates might ensure the maximum effectiveness of trap crops. Heavy infestations of the African bollworm on the trap crops need to be controlled to prevent build-up of the pest populations.

Trap cropping and planting diversionary hosts have been widely applied, although with variable results.

Some examples are given below:
Intercropping of cotton with chickpea, cowpea, onion, pearl millet, crotalaria, pigeon pea and marigold in strips is reported to divert the populations of sucking pests and the African bollworm from cotton (Dejen and Tesfaye, 2002).

It has been shown that flowering sunflower, sorghum and maize are much more attractive to African bollworm moths for egg-laying than cotton. For this reason, maize has been commonly used as a trap crop. Preference for maize has been observed to be so strong that cotton plots remained almost clear of eggs when bordered with a few rows of maize. However, this attractiveness appears to be inconsistent. This may be due to differences between varieties of the host plant or differences between African bollworm populations (van den Berg, 1993).

Studies of this pest and its natural enemies in cotton, sunflower, maize and sorghum in Kenya showed that survival of the African bollworm is low in maize and sorghum. Therefore, it is suggested that they could be used to divert African bollworm infestation. The selection of the variety is important. In the case of sorghum, studies in Tanzania showed that mortality of the African bollworm was high in sorghum varieties with open panicles, which give little protection from natural enemies. In contrast, pest mortality in compact head sorghum varieties with dense and semi-dense panicles was low. Cotton grown adjacent to compact head varieties suffered a rapid build-up of the African bollworm as the sorghum crop reached maturity (Nyambo, 1989). Moreover, when using maize or sorghum as trap crops to protect cotton, these trap crops would have to be planted at regular intervals since there is only a short period (flowering) when maize and sorghum are attractive to the moths, whilst on cotton, moths lay eggs over an extended period of time (three months in Kenya) (van den Berg, 1993). This would be feasible if irrigation is available but impractical for rain-fed crops.

Castor, sunflower, black gram and cowpea are also recommended as trap crops for cotton. These plants attract bollworms as well as provide habitat for natural enemies, which feed on bollworms. It has been recommended to grow a row of castor as border crop, or to sow one row of the other crop after every five rows of cotton (CIKS, 2000).

Research in Ethiopia indicated that lupin, pigeon pea, hyacinth bean, maize and sunflower attracted significantly higher numbers of this pest and diverted them from the main crop of haricot beans (Dejen and Tesfaye, 2002). It has been reported that maize grown as a strip crop at 10m intervals reduced pod damage by the African bollworm in haricot beans (Ahmed and Damte, 2002).

Intercropping chickpeas with wheat, barley, linseed, mustard and safflower are reported to reduce attack by the African bollworm on chickpeas in India. On the other hand, intercropping chickpeas with lentils and field peas have led to a higher pest infestation in chickpeas (Negash and Abate, 2002).

African marigold has been used as trap crop in tomato. Marigold planted after every eight rows of tomato helps attract most of the African bollworms moths to marigold (Negash and Abate, 2002).

The following procedure has been recommended to minimise infestation of the African bollworm on vegetable crops in Ghana (Youdeowei, 2002):
Obtain a suitable trap crop to plant with the main crop.

Plant the trap crop around the vegetable field in strips 10 to 15cm apart; pigeon peas can be planted as a hedge around the main crop Plant the trap crop so that it starts flowering earlier than the main crop and remains flowering thorough the development cycle of the main crop. This way, the bollworms will lay eggs and thrive only on the trap crops.

Regularly observe the populations of bollworms on the trap crop and, if necessary, spray them with a suitable, permitted pesticide to control them.

Crop rotation
Avoiding planting crops after each other that are susceptible to bollworm like cotton, maize, sorghum, tobacco, soybean and tomato may help to reduce/prevent buildup of bollworm populations. However, to be effective, crop rotation should be done over large areas, since the moths can fly long distances (Dobson *et al*. 2002). Some crops not susceptible to bollworm that could be planted in rotation with susceptible crops are small grains like rice and plants of the onion family.

In countries with two distinct seasons (wet and dry), it has been recommended to plant rice followed by beans during the rainy season and cotton or small grains in the second cropping (Hasse, 1986 and 1987).

However, it should be noted that the African bollworm also attacks many other plants commonly found in the field (e.g. weeds). Therefore, crop rotation alone is not likely to be effective in managing this pest.

3.6.5.5. Remedies
Biological pest control
Natural enemies
In Africa, a wide variety of natural enemies have been recorded attacking the African bollworm. The most important are egg parasitoids *(e.g. Trichogramma spp.)*, larval parasitoids (wasps and flies that parasitise caterpillars) and predators such as ants, assassin bugs, minute pirate *(anthocorid)* bugs, lacewings and ladybirds. Over 170 parasitoids and a large number of predators have been reviewed and catalogued, most of them from southern and East Africa (Cherry *et al*, 2003). Conserving and encouraging these natural enemies should be part of any strategy to manage this pest.

The distribution and importance of natural enemies vary within and between regions, between crops and seasons. For example, parasitism of eggs by *Trichogramma* wasps is higher and by more species on sorghum than on other crops. Studies in Kenya showed that predators, mainly *anthocorid* bugs and ants, were the most important natural enemies of the African bollworm on sunflower, maize, sorghum and cotton (van den Berg, 1993; Cherry *et al*. 2003), while in northern Tanzania, parasitism and diseases were the major cause of mortality on sorghum, cotton and a weed *(Cleome sp.)* (Nyambo, 1986, 1990; van den Berg, 1993).

Spraying practices can harm natural enemies. This is particularly detrimental early in the season since natural enemies that may otherwise have built up and suppressed the pest, are killed. Substitution of broad spectrum pesticides with selective bio-pesticides such as Bt, Nuclear Polyhedrosis Viruses (NPVs) and botanicals (e.g. neem), for control of this and other pests may permit the early establishment of natural enemies and contribute to the control of pests. To achieve better results, this should be a joint effort involving neighbours and farmer communities on a regional scale.

Plant crops that are attractive to natural enemies

The impact of natural enemies can be improved through intercropping or adjacent planting of crops that are attractive to them. In cotton, the African bollworm infests the crop before flowering; this is earlier than the immigration of *anthocorid* bugs into the fields. It is suggested that if crops with distinct flowering periods that attract African bollworm moths and *anthocorid* bugs at the same time, are planted adjacent or intercropped with young cotton, they would attract *anthocorid* bugs and other predators early in the season and at the same time, distract moths from cotton. Sorghum seems to be a better 'natural control' plant than maize because it is equally or more attractive to African bollworm and attracts more *anthocorid* bugs during flowering. Moreover, sorghum varieties are better adapted than maize to the dry climatic conditions where cotton is commonly grown (van den Berg, 1993).

Ants are important predators of the African bollworm. Ant activity on the crops can be encouraged by changing crop composition, by weed management and by the provision of alternative food sources. Plants that offer alternative food sources on the canopy, such as plant exudates or honeydew producing insects, are more attractive to ants. Ants could also be attracted to crops by providing crushed sugar cane, or a sprayed sugar solution. Ants would then complete their diet with protein by preying on insects, including the caterpillars of the African bollworm. A good example is the BioRe Project in Tanzania, where sunflower is used as a trap crop in and around organic cotton fields. Cannibalism and predation by ants (in particular the bigheaded ants *Pheidole* spp.) on sunflowers causes high mortality among bollworm caterpillars (Cherry *et al*, 2003).

Free range chickens can be used to eat caterpillars and pupae at certain times of crop development in small fields. They can be allowed to roam freely on lands that are not yet planted or where hardy crops are growing. However, they should not be allowed near seedlings or plants with fruit since they may cause damage by scratching and pecking (Dobson *et al*, 2002; Elwell and Maas, 1995). Birds that eat pests can be encouraged to visit crop fields. Some changes will encourage them to nest and stay in the area and this can lead to a permanent increase in local predatory bird populations. For example, groundnut plants are close to the ground and birds cannot use them as vantage points for spotting insect prey. From a perch, however, birds can easily identify prey and swoop down to devour insect pests off cotton, peanuts and cowpeas. Predatory birds prefer to look for prey in field crops where they have places to rest. To make bird perches, use bamboo or wooden poles or tree branches. Erect either of these at regular intervals in the field.

To have live bird perches within the field, plant *Setaria* species (foxtail cultivars). These plants have been found to be attractive to predatory birds. Much larger populations of birds (mynas, finches and blackjays) were recorded in fields with bird perches and these contributed to a significant suppression of the insect pests. In cotton field, plant Setaria in every 9th or 10th row of cotton. Once the birds are on the fields, they prey on cotton bollworms and other insects (NCIPM, 2000).

Bio-pesticides and physical methods

- ***Botanicals***

  Several plants are reported to be useful in the management of the African bollworm on several crops. Garlic is reported to be effective against African bollworm on cotton and maize.

  Experiments for screening effective botanicals for the control of tomato pests, in Western Kenya, indicated that pepper and marigold were effective against pests of tomatoes including African bollworm (Magenya, 2002).

- ***Neem (Azadirachta indica)***

  There are several reports of use of neem products for control of the African bollworm on several crops. It is important to control the small caterpillar before they enter the fruit, as any later treatment would be ineffective.

- ***Bt (Bacillus thuringiensis)***

  Bt is widely used in Africa for the control of caterpillars, including the African bollworm. In particular *B.t. subspecies kurstaki* and *B.t. aizawai* control this pest (Cherry et al, 2003; Kibata, 2002).

- ***Farmer's experience***

  In Kenya, farmers at the coast use extracts from neem leaves and seeds and commercial neem products on vegetable crops. They also use extracts from hot pepper or mixtures of plant extracts such as Lantana, chillies and Tephrosia (Kega, 2002; Pole and Kimani, 2002).

- ***Physical methods***

Handpick damaged fruits and collect those that have fallen from trees. Destroy the damaged fruits by cutting into small pieces, or place them in sealed black plastic bags and "cook" under the sun. Do not put them immediately in compost or bury them. This will enable the matured caterpillars to pupate into the soil
Handpick and destroy eggs and caterpillars. It is very important to detect small caterpillars before they enter the fruits. This is feasible at low infestations and on small plots
Weed if necessary. Destruction of weeds that may harbour caterpillars is important to prevent African bollworm infestation
Plough the field to expose the pupae to predators and the sun

3.6.6. Diamondback moth (DBM)

3.6.6.1. Scientific and common names

Plutella xylostella

3.6.6.2. What it is

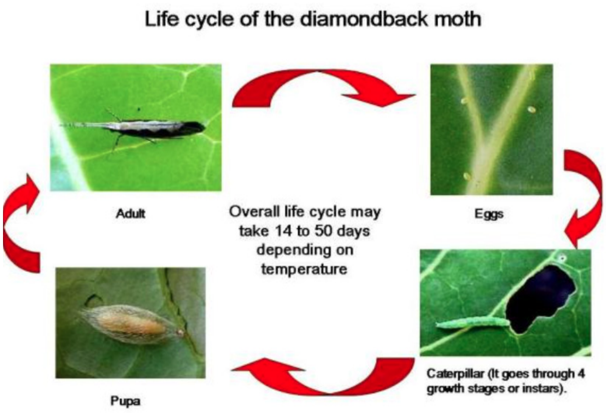
Diamond back moth eggs are tiny (less than 1mm), flat, oval in shape and yellowish in colour. They are laid singly or in groups of 2 to 3 along the veins on the upper and lower leaf surfaces of the host plants. The eggs hatch in 3 to 8 days, depending on the environmental conditions.

Caterpillars are pale yellowish-green to green covered with fine, tiny scattered, erect hairs. Mature caterpillars are cigar-shaped and about 12mm long and have chewing mouth parts.

The caterpillars go through four instars and complete their development and pupate in

10 to 28 days. Diamond back moth (DBM) caterpillars are easily identified because they wriggle violently when disturbed, drop from the plant suspended by a silken thread and finally climb their way back up and continue feeding.

Diamondback caterpillars feeding on kale



Diamondback moth life cycle

Pupae are 5mm to 6mm long. Pupae are initially light green and turn brown as the adult moths become visible through the cocoon. They are covered with a loosely spun net-like cocoon that is attached to the leaves, stems or seedpods of the host plant. Cocoons are about 9cm long.

The moths emerge 3 to 15 days after pupation depending on the environmental conditions.

Diamondback moth damage on cabbage

The adult is a small greyish-brown moth, approximately 8mm to 9mm long with a wingspan of 12mm to 15mm. It has diamond-shaped markings on the back when the wings are folded, which gives the common name to this insect. The moth folds its wings over the abdomen in a tent-like manner when resting. The wing tips are fringed with long hairs. Adult females can lay an average of 160 eggs during their lifespan of about 16 days. Moths lay eggs at night. The greatest number of eggs is laid in the first nights after emergence, egg laying continues for about 10 days. In the field, moths will fly out of the plant canopy when disturbed.

Diamondback moth pupae

Diamond back moth infestations tend to be serious in the dry months. Heavy rains may reduce populations dramatically, thus this pest is less likely to be a problem in wet years and during rainy seasons. Diamond back moth populations can increase rapidly at temperatures above 26°C.

3.6.6.3. The damage caused

Symptoms

Newly hatched DBM caterpillars feed as leafminers inside the leaf tissue. Older caterpillars feed on all plant parts. They feed on leaf tissue leaving the upper leaf surface intact. This type of damage is called "windowing", since it gives the appearance of translucent windows on the leaf. In cases of severe infestation, entire leaves could be damaged. Caterpillars and pupae are found on damaged leaves. Older caterpillars are often found around the growing bud of young plants and their feeding can deform the plant. DBM caterpillars also feed on stems and pods. Heavy damage results in the marketable parts contaminated with excrement, which makes the produce unsalable.

Diamondback moth adult

Throughout the world, the diamondback moth is considered the main insect pest of brassica crops, particularly cabbages, kales, broccoli and cauliflowers. The economic impact of the diamon dback moth is difficult to assess since it occurs in diverse small scale and large-scale production areas, but it has been known to completely destroy cabbage and kale crops. It is considered a major pest in all countries of the eastern and southern African region.

Affected plant stages

Seedling stage, vegetative growing stage, flowering stage and fruiting stage

Affected plant parts

Fruits/Pods, growing points, inflorescence, leaves and stems

3.6.6.4. Cultural practices to prevent its occurrence

Cultural practices

- ***Monitoring***

  Inspect the crop regularly. Diamond back moth populations can increase rapidly in warm conditions. Therefore, it is important to scout for DBM regularly, at least twice a week. DBM caterpillars are detected by visual observations of the plant and adults can also be detected using pheromone traps although they might not be suited for use under cover.

  Scouting should begin when the plants are young; the earlier the pest is discovered, the easier it is to control. Plants should be checked thoroughly. Growing points should be carefully examined. Caterpillars that are inside the cabbage head are difficult to detect unless outer leaves are pulled back. When scouting, it is important to record presence of parasitic wasps and parasitised caterpillars.

- ***Examples of economic thresholds***

  Economic thresholds for the DBM have been developed in several countries. For example, in small cabbage plots (0.25ha) in Honduras, it is recommended to sample at least 60 plants and the action threshold is one caterpillar per plant. Broccoli and cauliflower at the vegetative stage can support 30% defoliation. At harvest time, an infestation level of one caterpillar per head is the action threshold (Rueda and Shelton, 1995). In the Midwest (USA), the treatment threshold for caterpillars (including DBM) attacking cabbage is given as 10% of infested plants in the seedbed, 30% infested plants from transplant to cupping stage, 20% infested plants from cupping to early heading and 10% infested plants at early heading to mature head stages. For processing cabbage, which will be trimmed and shredded, more injury is tolerable; treatment is advised at 75% infestation. The treatment thresholds for broccoli and cauliflower are: 10% plant infestation in the seedbed, 50% plant infestation from transplant to first flower and 10% infestation from first flower to maturity (Foster and Flood, 1995).

These thresholds are given as examples. However, note that economic thresholds depend on many factors (crop stage, crop age and economic and climatic conditions) and cannot be adopted without taking into consideration local conditions.

Sanitation

Start with a healthy crop. Place seedling beds away from production fields to minimise attack by the DBM. Transplant only healthy seedlings, which are free of eggs, caterpillars and pupae of the DBM and other pests.

Remove and destroy or plough down crop residues in seedling beds and production fields.

These practices will prevent build-up of the DBM and migration to nearby fields.

Pest avoidance

Planting cabbage at the beginning of the rainy season can help to avoid problems with the DBM. Heavy rains reduce flight activity and mating of moths and wash off caterpillars and pupae from plant leaves. However, in the rainy season, the plants will be more prone to diseases such as black rot, downy mildew and ring spot.

Crop rotation

Crop rotation can be effective in controlling the diamondback moth in semi-arid environments as there are only very few wild host plants. A significant reduction in the number of caterpillars can be achieved by having a break of 6 weeks or more where no brassica crops (cabbage, broccoli, cauliflower, among others) are grown at all.

It is important that all farmers in a locality, or at least close neighbours, follow crop rotation simultaneously. This break will disrupt the pest's breeding cycle. Therefore, brassica crops planted after this break will be safe from the pest for some time. However, this does not work in the highlands where large numbers of wild host plants are present in the surroundings of the fields throughout the year.

Intercropping, trap cropping

Planting rows of tomatoes alternately with rows of cabbage is reported to reduce damage but it does not prevent the attack completely. Kenya Institute of Organic Farming recommends this method as effective. In addition, cabbages would repel the tomato bollworm, making this practice serve a double purpose.

Intercropping with chillies is said to repel DBM adults (Dobson *et al*, 2002).

Trap crops such as mustard and rape can also be useful to reduce DBM attacks. Fifteen rows of cabbage followed by mustard rows have been shown to be most effective (HDRA, 2000). Bold seeded Indian mustard could also be sown densely all around the area 10 days before the crucifers are planted. The plants attract up to 80% of DBM (IPM Bulletin of Pest Management, Undated). However, trap crops should be frequently monitored so as to control this pest before it can move to the main crop. Once the trap crop is infested, it can be ploughed in or removed. Unattended trap crops can generate large populations of DBM.

Care is needed to manage intercrops in order to use them as part of a control practice (Shelton *et al*., 1995).

Irrigation

As with rain, frequent overhead irrigation disrupts moth activity and washes off caterpillars from the plants. However, use of sprinkler irrigation may lead to increase of diseases such as black rot and downy mildew.

Habitat management

Managing the habitat or the way a crop is grown helps to prevent or reduce pest and disease. Mix cropping brassica crops with some other crops or plants (intercropping, trap crops, strip cropping) has been shown to reduce infestation by the DBM. The plants to be grown together with the brassica crops need to be carefully selected. Onions and tomatoes can be intercropped with brassicas.

By the maintaining natural surroundings, including trees and shrubs, natural enemies are conserved by providing shelter and plenty of breeding places for them to breed. Maintaining strips of local flowering plants in the vicinity of the brassica crops is useful for beneficial insects. Trap cropping with flowering mustard can also augment the number of beneficial insects in the trap crop and the neighbouring crops.

3.6.6.5 Remedies

Biological pest control

Natural enemies

Natural enemies (local and imported) can help to keep the pest at acceptable levels if they are conserved and their activity encouraged. Habitat management and avoidance of broad-spectrum insecticides early in the season, when the DBM is present in low numbers, may preserve natural enemies that can help keep DBM and aphid populations under control later in the season.

Many natural enemies prey on the DBM at different stages of its life cycle. Birds and spiders feed on moths; ants, lacewings, wasps and parasitic wasps among others attack the caterpillars.

Numerous parasitic wasps attack diamond back moth. The most common are wasps of the genus *Cotesia, Diadegma, Diadromus* and *Oomyzus*. These wasps are also known African species and some are reported to effect excellent control of the DBM elsewhere.

Unfortunately, local wasps do not provide satisfactory control of the diamond back moth in eastern and southern Africa. For this reason, two species of wasps *(Diadegma semiclausum* and *Cotesia plutellae)* were imported and released by the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya, Uganda and Tanzania. The former has provided almost complete control of this pest in highland growing conditions while the second is specific to mid-altitude, semi-arid areas where it also provides good control.

It is important to distinguish parasitised DBM caterpillars from healthy ones. Caterpillars parasitised by *Diadegma semiclausum* can be distinguished at the pupal stage. The larva of this parasitic wasp eats the DBM caterpillar from inside and pupates inside the DBM cocoon. The pupa of the parasitic wasps appears as a round elongated brown capsule within the DBM cocoon. In contrast, it is possible to see the developing moth through the cocoon of a healthy pupa.

The larva of *Cotesia plutellae* feeds inside the DBM caterpillar and emerges from the caterpillar to pupate in a silky cocoon on the leaves near the dead diamondback moth caterpillar.

Bio-pesticides and physical methods

Pathogens including fungi, bacteria and viruses are naturally found to cause diseases in the diamond back moth in the field. However, they generally occur during rainy seasons when problems with this pest are not very pronounced.

Bt (Bacillus thuringiensis)

Bacillus thuringiensis var. aizawai and *Bt var. kurstaki* are very effective in controlling infestations of the DBM. *Bt var. kurstaki* is widely used at a weekly interval and a rate of 0.5/ha. This type of strategy provides effective control of this pest. However, continuous use of Bt can induce resistance. Bt kills the DBM and does not harm beneficial insects. Bt insecticides should be applied when the newly hatched caterpillars appear. Sprays may need to be applied at intervals of 5 to 7 days when populations are high. Because Bt insecticides are UV-degradable, treat crops in the late afternoon.

Farmer's experience

Farmers in some countries produce their own homemade bio-pesticides by collecting diseased DBM caterpillars (fat and white or yellowish or with fluffy mould on them), crushing them and mixing them with water in a blender. Large tissue clumps are filtered out and the liquid is sprayed onto the crop (Dobson et al, 2002).

Neem (Azadirachta indica)

Neem-based products give good control of the diamondback moth and are relatively harmless to natural enemies and non-toxic to warm-blooded animals. Since the action of neem is relatively slow, caterpillars may survive for a few days after application, but their growth and feeding is inhibited and they do not cause further damage to the crop.

3.6.7. Aphids

3.6.7.1. Scientific and common names

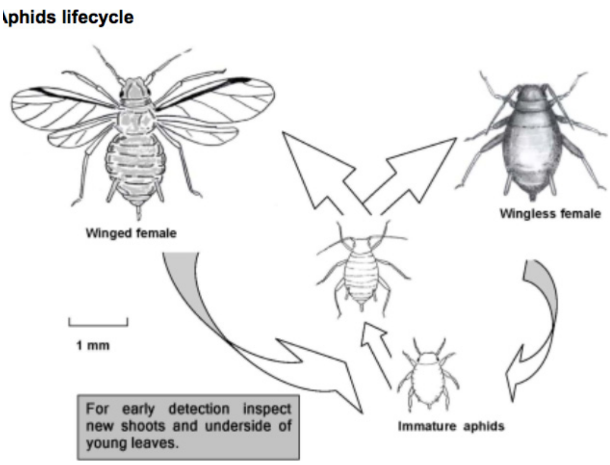
Aphis gossypii, Aphis spiraecola, Acyrthosiphum pisum, Brevicoryne brassicae, Cinara cupressi, Diuraphis noxia, Lipaphis erysimi, Melanaphis sacchari, Myzus persicae, Pentalonia nigronervosa, Ropalosiphum maidis, Toxoptera aurantii, Toxoptera citricida

3.6.7.2. What it is

Aphids have complicated life cycles. Females can reproduce with or without mating. Female aphids may lay eggs or give birth to wingless offspring, known as nymphs. In warm parts of the world, as in the tropics, no male aphids are produced and female aphids do not lay eggs but give birth to small nymphs. A female can produce from 20 to over 100 nymphs. Young aphids grow quickly, becoming adult in about one week and start to reproduce. Thus, their numbers increase rapidly under favourable conditions.

Aphids live in clusters (known as colonies) on leaves and stems. Initially they are present on tender parts of the plant (young shoots and leaves), but as their number increases they can cover the whole plant. As the colony grows, winged aphids are produced which fly away looking for new plants to start a new colony.

Eggs are very tiny, shiny-black and are found in the crevices of bud, stems and barks of the plant. Aphids usually do not lay eggs in warm parts of the world.



Aphids life cycle

Nymphs (immature stages) are young aphids; they look like the wingless adults but are smaller. They become adults within 7 to 10 days.

Adults are small, 1mm to 4mm long, soft-bodied insects with two long antennae that resemble horns. Most aphids have two short cornicles (horns) towards the rear of the body. Their mouthparts are needle-sharp, resembling tiny straws. Their body colour varies from black, green, red, yellow, pink, white, brown, greyish or purple. Adults of the same species may be wingless or winged (with two pair of wings). Winged aphids are usually dark in colour. Wingless forms are the most common; winged aphids are produced when they need to migrate, for example under overcrowded conditions with limited food source or when environmental conditions are unfavourable.

Adult Aphid

Warm and dry weather is particularly favourable for rapid increase of aphid numbers.

Major species of aphids attacking crops in Africa:

Banana aphid *(Pentalonia nigronervosa)*
Black bean aphid *(Aphis fabae)*
Cabbage aphid *(Brevicoryne brassicae)*
False cabbage aphid *(Lipaphis erysimi)*
Citrus aphid *(Toxoptera citricidus, T. aurantii)*
Green peach aphid *(Myzus persicae)*
Groundnut aphid *(Aphis craccivora)*
Cotton aphid (Aphis gossypii)
Russian wheat aphid *(Diuraphis noxia)*
Cypress aphid *(Cinara cupressi)*
Mango aphid *(Toxoptera odinae)*
Maize aphid *(Ropalosiphum maidis)*
Pea aphid *(Acyrthosiphum pisum)*
Sorghum aphid *(Melanaphis sacchari)*

3.6.7.3. The damage caused

Symptoms

Both adults and nymphs pierce plant tissues to feed on plant sap. Their feeding may cause rolling, twisting or bending of leaves. Heavily attacked leaves can turn yellow and eventually wilt. Aphids feeding on flower buds and fruits may cause malformed flowers and fruits. Aphids excrete a sugary, sticky liquid called honeydew that accumulates on leaves and branches. Sooty moulds (a fungal growth) grow on honeydew deposits turning leaves and branches black. Heavy coating with honeydew and sooty moulds may reduce photosynthesis, affecting plant growth and yield.

Honeydew is a favourite food of some ant species. Thus, black ants are commonly found on plants with aphid infestations. These ants protect the aphids from natural enemies and are therefore considered indirect pests. Ants may even transport aphids from plant to plant. Many species of aphids have been implicated as major vectors of plant viral diseases.

Aphids and ant

Affected plant stages

Seedling stage, vegetative growing stage flowering stage and generative stage

Affected plant parts

Growing points, stems, leaves, inflorescences, fruits and whole plant

Symptoms on affected plant parts

Curled leaves, abortion of flowers, stunted growth and dieback. Sooty black mould becomes evident in heavy infestations. Black ants are very common in plants with aphid infestations. However, sooty moulds and ants are also associated with other honeydew-producing insects such as mealybugs, scales and whiteflies

3.6.7.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

It is particularly important to scout crops during the critical periods of seedling and shoot growth and during flowering and fruiting. To monitor aphid populations, examine the undersides of the leaves and the bud areas for groups or colonies of aphids. The presence of ants may indicate the presence of aphids. Early detection of aphids is important as they can multiply rapidly. Therefore, the crop should be scouted regularly. Yellow traps are useful for monitoring the arrival of winged aphids to the crop. The presence and abundance of natural enemies should also be recorded.

Aphids on leaf

Economic Threshold Levels

Economic threshold levels have been developed for some aphid species. One example is the threshold level for cotton aphid *(A. gossypii)* on cotton in Sudan; if 30% of the plants are infested during the first 2 months of the season, treatments are recommended (Stam et al., 1994). However, damage thresholds depend on many factors (crop stages, crop age, economic and climatic conditions).

Instead of trying to use threshold levels, the growth of the aphid population within 3 to 5 days should be monitored. If a rapid growth of the number of aphids per plant is observed and no or only few predators (e.g. ladybirds, lacewings) are present, treatments should be planned. Most plants can tolerate moderate numbers of aphids without great damage. However, even small numbers may need to be controlled in cases where aphids transmit viral diseases. Prompt control is necessary when numbers build-up and natural control is not satisfactory.

Field sanitation and management

Grow healthy plants. Healthy plants are able to protect themselves better from pests and diseases than weak plants. Growers are strongly recommended to use compost in preference to manures, including liquid manures. Excess use of manures and mineral (artificial) fertilisers, particularly nitrogenous fertilisers, produces fleshy plant tissue that is attractive to aphids. Therefore their use should be avoided as far as possible.

Practice crop rotation. This may help to reduce aphid infestations; particularly of aphid species that are host specific (they feed and develop only on one or few plant species).

Grow crops in mixed cropping. This involves plant diversity by growing diverse plants on the same land and at the same time. Common mixed cropping includes the use of companion planting and intercropping. The mixture of plants needs to be carefully chosen. For instance, intercropping poses a problem when the minor crop harbours a disease or pest of the primary crop. Mixed cropping is in general beneficial to natural enemies, since it provides food and shelter. Depending on the plants used and the pattern of cropping, mixed cropping may help disrupt the lifecycle of pests and maintain their population below the economic threshold level. An example of a good intercrop in cabbage production is onions.

Use trap crops. Some crops are particularly attractive to pests and can be used to trap them and protect the main crop. Monitoring of the trap crops is very important. They should be destroyed when they become severely infested and before they are killed by the pest, or have completed their lifecycle, as the pest may move from the trap plants to the main crop. They can be removed and buried. Trap crops can be planted around the field to be protected, or interspersed among the rows.

Farmer's experience

Following are some examples of crop mixtures that are reported to help in managing aphid infestations:

Trap crops such as dill, nasturtiums and timothy grass near the main crop are reported to repel aphid infestations in the main crop (The Bug Lady, 2004).

Anise, chives, garlic, onions, radish and parsley are reported as good companion crops (Elwell and Maas, 1995; KIOF). Onion, chives, garlic and Mexican marigold repel aphids. The Kenya Institute of Organic Farming (KIOF) recommends leaving a few plants of Mexican marigold between the crops.

Intercropping beans with maize is a common practice in Africa. It has been shown that infestations of black bean aphid in common beans were greatly reduced when intercropped with older and taller maize plants in a study in Kenya (Ogenga-Latigo et al., 1993).

Numbers of the aphid *Aphis gossypii* decreased in potatoes that were intercropped with onions *(Allium cepa* or *Allium sativum)*. To achieve this reduction, the onions had to be planted within 0.75m of potato plants (Potts MJ, Gunadi N, 1991).

3.6.7.5. Remedies

Biological pest control

Natural Enemies

The most important aphid predators are predatory bugs *(e.g. Anthocoridae, Miridae, Nabidae)*, carabid beetles *(Carabidae)*, soldier beetles *(Cantharidae)*, predatory gall midges *(Cecidomyiidae)*, lacewings *(Chrysopidae)*, ladybird beetles *(Coccinellidae)* and hoverflies *(Syrphidae)*.

In addition, parasitic wasps (parasitoids) are often involved in the control of aphid populations. Parasitised aphids are easily recognised; they turn brown and hard and remain stuck to the plant surface and are known as "mummies".

Depending on climatic conditions and crops, fungi that cause diseases of insect pests (entomopathogenic fungi) can contribute to a rapid decline of aphid populations. Natural aphid enemies usually appear with a certain delay because they react to the presence of aphids.

It is important to help natural enemies to establish and improve their effectiveness (conservation biocontrol). This can be done through:

- Habitat management. For instance, leaving or growing flowering plants at the border of the crops or as companion plants within the crops that attract beneficial insects

- Avoiding the use of pesticides that are toxic to natural enemies. If pesticides must be used, selective Bio-pesticides that target specific pests should be preferred to broad-spectrum pesticides (that kill a wide range of insects including natural enemies).Controlling ants that feed on honeydew produced by aphids. They disturb natural enemies giving protection to the aphids. Ploughing and flooding the field destroys ant colonies and exposes eggs and larvae to predators and sunlight (Elwell and Maas, 1995)

Bio-pesticides and physical methods

Neem

Neem extracts can control early infestations of some aphids, but they are not efficient against all aphid species. For reliable and satisfactory control, neem extracts must be applied at an early stage of aphid attack. Usually, repeated spot sprays of affected plants are necessary to achieve control. Neem has a slow mode of action and usually effects are not visible before 10 days after application. Some neem extracts (e.g. oil extracts) may be phytotoxic. Therefore, test the extract on a few plants before going onto full scale spraying.

Neem products have in general no or low negative effect on natural enemies. However, products based on neem oil have stronger effects on some natural enemies.

Botanicals

Other botanical sprays reported to be effective against aphids include:

Chilli pepper

Cut ½kg of hot chilli peppers into small pieces and boil them in 4 litres of water for 20 minutes. Add equal amounts of soapy (bar soap) water, cool and spray (KIOF), or Pulverise 100g chillies in a mortar, shake vigorously in 1 litre of water and filter through a cloth. Dilute 1 part of this mixture with 5 parts of soapy water before spraying (G. Stoll, 1988).

Chilli also repels ants.

Castor oil plant

As a general spray, soak green leaves and seeds in water for 24 hours, filter and spray (Elwell and Maas, 1995).

Pyrethrum

Commercially available pyrethrum sprays are effective against aphid infestations, but also kill predators. It is therefore recommended to inspect plants regularly and control early outbreaks, before the insect becomes a big problem. Use spot sprays on infected plants.

Traps

Yellow sticky traps and yellow water traps are mainly used to monitor winged aphids. As the yellow colour attracts many insect species, including beneficial insects, use these traps only where necessary.

Water traps

Half-filled yellow pans or basins with soapy water are placed close to the plant but exposed enough so that aphids are attracted by the yellow colour. Water traps are mainly used to monitor winged aphids. As the yellow colour attracts many insect species, including beneficial insects, use water traps only where necessary.

Sticky board traps

To make your own sticky trap, spread petroleum jelly or used motor oil on yellow painted plywood, 6cm x 15cm in size and up. Place traps near the plants but far apart enough to avoid leaves sticking to the board. Sticky yellow traps are mainly used to monitor winged aphids. As the yellow colour attracts many insect species, including beneficial insects, use sticky board traps only where necessary.

Soap (fatty acids) spray

- Spray with insecticidal soaps or with a soap and water solution. This controls aphids and does not seriously affect natural enemies
- Mix 1 tablespoon of dishwashing soap or 3 tablespoons soap flakes (non detergent) with 4 litres of water. Add soap to water. Use mild soap or potash-based soap.
- Start with a lower concentration and make adjustments of the strength after testing on few infested plants
- Always try on few infested plants before going into full scale spraying. Soaps can cause burning of leaves (phytotoxicity) on sensitive plants, like brassicas and certain ornamentals. Make 2 or 3 treatments in a 3 to 4 day interval for better efficacy
- Apply on the infested plants thoroughly, including the undersides of the leaves. Spray early in the morning or late afternoon to avoid phytotoxic effects on crops
- Precaution: Soap spray may injure foliage. Test these sprays on few leaves before applying to the entire plant. It may take 2 days for symptoms of damage to appear

Others

Flour preparation

Flour mixed in water is said to be very effective against aphids and spider mites. It should be applied in the morning, taking care to spray underside of leaves. As the heat of the sun increases, the mixture dries out and the insects are left encrusted in flour, and shrivel and die. The coating of flour falls off the leaves so that their ability to photosynthesise is not essentially affected (Gabriele Stoll, 1988).

Ash

Ash can be used to effectively control aphids in vegetables. Ash should be dusted evenly onto infested parts of vegetables. Aphids can also be controlled by spraying wood ash mixed with soapy water and/or lime (Elwell and Maas, 1995).

3.6.8. Grasshoppers

3.6.8.1 Scientific and common names

Giant grasshopper *(Acanthacris ruficornis)*
Foam grasshopper *(Orthoptera family)*
Stone grasshopper
Variegated grasshopper *(Zonocerus variegatus)*
Elegant grasshopper *(Z. elegans)*

3.6.8.2. What it is

Variegated grasshopper *(Zonocerus variegatus* – West to East Africa south of the Sahara), and the elegant grasshopper *(Z. elegans)* (Southern Africa and East Africa) are brightly coloured grasshoppers.

Adults are dark green with yellow, black and orange marking on their bodies. Nymphs are black with yellow markings on the body, legs and antenna and wing pads. Female grasshoppers lay many eggs just below the surface of the soil in the shade under evergreen plants, usually outside cassava fields. Eggs are laid in masses of froth, which harden to form sponge-like packets, known as egg pods, which look like tiny groundnut pods. Eggs start to hatch at the beginning of the main dry season.

3.6.8.3. The damage caused

Grasshoppers attack a wide range of crops mainly in the seedling stage. They feed on cassava plants, chewing leaves and stems and may cause defoliation and debark stems. This

Grasshopper life cycle Art Cushman, USDA Systematics Entomology Laboratory, Bugwood.org

is particularly severe in fields next to the bush when the dry season is prolonged.

Grasshoppers and locusts attack maize from the mid-whorl stage to maturity and may consume every part of the plant. Attacks vary in severity from location to location.

3.6.8.4. Cultural practices to prevent its occurrence

- Conserve natural enemies. Avoid destroying the larvae of blister beetles,

Grasshopper damage - R.J. Reynolds Tobacco Company Slide Set, R.J. Reynolds Tobacco Company, Bugwood.org

Grasshopper on maize - Art Cushman, USDA Systematics Entomology Laboratory, Bugwood.org since they feed on the eggs of grasshoppers. Other natural enemies include ants, parasitic flies, assassin bugs, predatory wasps, birds, lizards, snakes, frogs and fungi. Robber flies are a major predator of grasshoppers

- Domesticated poultry (e.g. chickens, turkeys, guinea fowl, geese and ducks) and wild birds are good for keeping grasshopper populations in check. However, birds may damage the plants too. To avoid this, enclose the birds in wire fencing along the perimeter so that they can prey on visiting grasshoppers while staying out of the crop
- Ensure the ground is covered with crops, grass or mulch. This is reported to reduce grasshopper numbers since they prefer laying eggs on bare soil
- Locate and dig egg-laying sites to expose and destroy the eggs before they start to hatch early in the dry season. However, egg pod destruction has to be done over a wide area in the wet season in order to be effective. This will require participation of farmers on many neighbouring farms. If only one neighbour destroys the eggs in his/her farm, the grasshoppers will later invade the farm from the neighbouring farms and bushes
- Catch grasshoppers by hand or with a butterfly net. Catching them in the early morning is easier, as they are less active in the mornings
- Dig or cultivate the land before planting to expose the eggs to predators and to the sun

3.6.8.5. Remedies

Bio-pesticides

Neem extracts act as anti-feedant (grasshoppers stop feeding when exposed to neem products) and affect the development of grasshoppers.

IITA researchers and partners have developed an environmentally friendly bio-pesticide "Green Muscle" based on a naturally occurring fungus strain indigenous to Africa *(Metarhizium anisopliae)*. This fungus is deadly to locusts and grasshoppers but reportedly does not damage plants, animals - or people. Typically 70% to 100% mortality rates were obtained after 8 to 28 days of application *(www.iita.org)*.

In Nigeria, the following neem products have given good control of *Z. variegatus* on cassava:

1. Emulsifiable concentrate of neem oil at 0.5 to 2% applied at 8-day intervals or at 3 to 4% at 10-day intervals

2. Aqueous neem kernel water extracts (NSKE) at 7% to10% applied every 12 days and aqueous neem leaf water extracts (NLWE) 50% applied every 6 days. Aqueous extracts from neem leaves were less effective than neem seed extracts (Olaoifa and Adenuga, 1988)

3.6.9. Bagrada bug

3.6.9.1. Scientific and common names

Bagrada cruciferarum, Bagrada hilaris
Bagrada bug, harlequin bug, painted bug, stinkbug

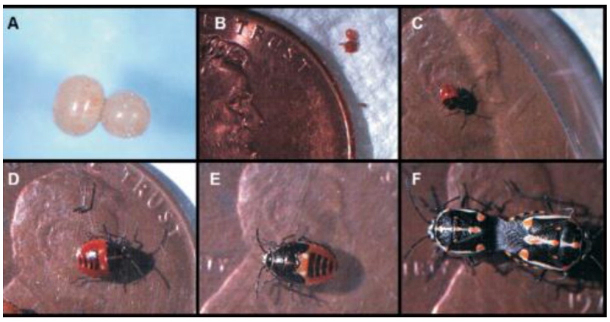
3.6.9.2. What it is

The bagrada bug lays its eggs in clusters on leaves or on the soil underneath host plants. Eggs are barrel shaped, initially white and turn orange with age. A single female can lay as many as 100 eggs within 2 to 3 weeks. The incubation period is 5 to 8 days.

Nymphs pass through five stages, changing colour from bright orange to red with dark markings, gradually acquiring the colouration of the adult. Initially they do not have wings; wings are gradually developed as the nymphs grow. Wing pads are visible in the last instar nymph.

The adult bug is typically shield-shaped, 5mm to 7mm long and 3mm to 4mm broad at its widest area. The upper surface has a mixture of black, white and orange markings, which gives the insect its common names harlequin bug or painted bug.

Bagarada bug - GEVORK ARAKELIAN, LA County Dept. Agriculture, Bugwood.org



Life stages of Bagrada bug

The life cycle lasts 3 to 4 weeks and several generations may occur in a year.

The bagrada bug is a common stinkbug on cabbage, kale, rape, chinese cabbage, turnips and other crucifers such as radish. It also attacks potatoes, beetroot, papaya, maize, sorghum and pearl millet, legumes and cotton. It has also been recorded as an occasional pest on groundnuts, wheat and rooibos tea. The bagrada bug has also been reported as a pest of capper *(Capparis spinosa)* (Colazza et al. 2004).

3.6.9.3. The damage caused

Bagrada bugs damage plants by feeding on young leaves. Both adults and nymphs suck sap from leaves, which may wilt and later dry. Considerable damage is caused to young plants, which may die or have the growth points severely damaged. Significant damage may also be caused to older plants.

Bagrada bugs are major pests of cultivated crucifers. Severe infestations on cabbage result in stunted plants, leaves turning yellow with a rough texture and death of the growing point. As a result, damaged plants do not produce heads or produce two or more small unmarketable heads instead of a large central head.

The bugs, especially in the early stages of development, gather in masses and suck the sap from plants. Feeding by the bugs causes small puncture marks, visible as white patches starting on the edges of leaves. Eventually the leaves wilt and dry. Heavily attacked plants may have a scorched appearance.

Bagrada bug damage

3.6.9.4. Cultural practices to prevent its occurrence

Monitoring

Regular monitoring of the crop is important to detect bagrada bugs before they cause damage to the crop.

Research in Namibia has shown that control measures should start if the number of bugs/ m^2 in the early growing stage exceeds one. If the crop is past the early growing stage, a higher threshold level of 3 bugs/m² can be maintained (Keizer and Zuurbier). However, note that these thresholds are given as examples. Economic thresholds depend on many factors (crop stage, crop age and socio-economic and climatic conditions) and cannot be adopted without taking into consideration local conditions.

Field sanitation

Crop hygiene, in particular removal of old crops and the destruction of weeds of the *Cruciferae* family prevents population build-up.

Hand picking

Handpicking and destruction of the bugs helps to reduce damage. This is particularly important in the early stages of the crop. Hand picking is only practical on small plots.

Cultivation

Eggs laid in the soil are readily killed by cultivation. Frequent, light cultivation (once or twice a week) of the vegetable beds will help in controlling this pest (Keizer and Zuurbier; Horticultural Research Program, Botswana).

Irrigation

Watering and overhead irrigation disturb the bugs, discouraging them from feeding on the crop. However, note that use of sprinkler irrigation may lead to an increase of diseases such as black rot and downy mildew.

Mixed cropping

Growing strong smelling plants such as garlic, onion or parsley near the crop are reported to reduce infestations (Dobson et al, 2002).

3.6.9.5. Remedies

Biological pest control

Natural enemies

Eggs of bagrada bugs are parasitised by tiny wasps and flies *(e.g. Alophora spp.)*.

Bio-pesticides and physical methods

Plant extracts

A mixture of chilli, soap, garlic and paraffin has shown to be an effective control method in trials in Namibia (Keizer and Zuurbier).

Natural products

In Namibia there are reports that sprinkling the plants with crushed bagrada bugs repels other bugs. This can be used effectively in combination with frequent soil cultivation (Keizer and Zuurbier).

Soap solution

Spraying plants with a soapy solution (bar soap) has been found to be effective against bagrada bugs and helps to wash off young bugs (Dobson et al, 2002; Elwell and Maas, 1995).

3.6.10. African maize stalkborer

3.6.10.1. Scientific and common names

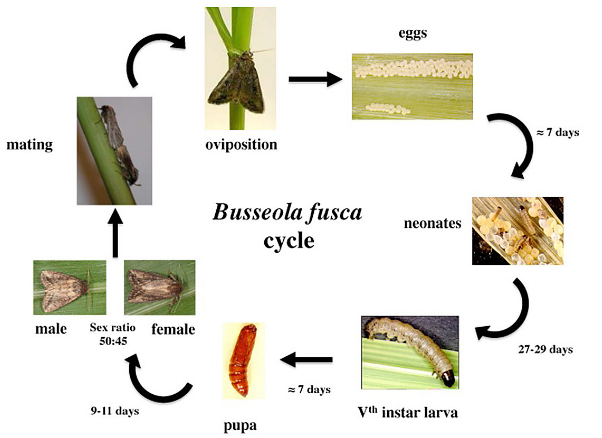
Busseola fusca (Fuller)
Maize stem/stalk borer, sorghum stalk/stem borer

3.6.10.2. What it is

Busseola fusca is indigenous to Africa. Its distribution and pest status varies in each region. In East and southern Africa, it is a pest at higher altitudes (above 600m), but in Central Africa it occurs from sea level to over 2 000m, while in West Africa it is primarily a pest of sorghum in the dry Savannah zone.

African maize stalkborer's eggs are round, flattened and about 1mm in diameter. They are usually laid in batches of 30 to 100 under leaf sheaths in a long column stretching up the stem and may be slightly compressed by pressure from the growing stem. They are white when first laid but darken as they age. Eggs hatch in about 7 to 10 days.

Caterpillars are light or dark violet to pinkish white in colour, often with a distinctive grey tinge. They lack conspicuous hairs and look smooth and shiny, but have rows of small black spots along the body. On hatching, caterpillars are blackish. They crawl up the plant into the funnel where they feed on leaves for 2 to 3 days and then either move to other plants or enter the maize stem.



maize stalkborer -www.mdpi.com

African Maize Stalkborer

African Maize Stalkborer eggs

After the caterpillars bore into the maize stems, they feed and grow within the stems for 2 to 3 weeks. They grow to a length of about 40mm. When fully grown, they cut a hole in the side of the stem before pupating within the tunnel inside the maize stem.

The total larval period is usually 35 days when conditions are favourable during the growing season, but during dry and/or cold weather caterpillars enter into a resting period (diapause) of 6 months or more in stems, stubble and other plant residues. At the onset of the rains, the caterpillars pupate within the stems.

Pupae are shiny yellow-brown to dark brown and about 25mm long. After 7 to14 days the adults emerge from the pupae and come out of the stem.

The adults have a wingspan of about 25 to 35mm. Females are generally larger than males. The forewings are light to dark brown with darker markings and the hind wings are white to greyish-brown. There is much seasonal and geographic variation with darker colouration developing in cold wet conditions.

Adult moths of stemborers are seldom seen in fields, as they are inactive during daytime. They become active after sunset and lay their eggs at night.

They have several generations in a year, so their numbers increase towards the end of the season.

The main hosts of the African stalkborer are maize and sorghum. This stemborer is also a pest of pearl millet in Mali, Burkina Faso and Eritrea. It also attacks few grass species, wild sorghum species mainly, but it is rarely found in natural habitats.

3.6.10.3. The damage caused

Damage is caused by the caterpillars, which first feed on young leaves, but then enter the stems. During the early stage of crop growth, the caterpillars may kill the growing points of the plant, causing what is known as dead-heart, where the youngest leaves can be easily pulled off.

At a later stage of growth, they make extensive tunnels inside the stem. This disrupts the flow of nutrients to the grain. Tunnelling weakens the stem so that it breaks and falls over. In older plants the first generation caterpillars bore in the main stem but later some of the second generation bore into the maize cobs. Caterpillars also tunnel into the peduncles of sorghum and millet inflorescences and may seriously affect grain production.

Because maize plants do not produce tillers, they are less able to tolerate a stem borer attack than sorghum and pearl millet plants and the effect on grain yields is therefore greater.

Colonisation of the plant by borers, and the severity of infestation and damage strongly depend on the cropping system and soil fertility, which affects the nutritional status of the plant.

Stemborer damage is aggravated by the poor nutritional status of the plant.

Studies on several stemborers in Africa showed that an increase in nitrogen is related to higher pest loads and tunnel damage. However, soil nutrient levels, such as nitrogen, greatly influenced the plant's tolerance to a stemborer attack. This is due to an increase in plant vigour, which is reflected in lower yield losses (Setamu *et al*., 1995).

Damage caused by stemborers can average between 20% and 40%, which means between 2 to 4 bags of maize are lost out of every 10 that could have been harvested. Grains damaged by pests such as stemborers become susceptible to infection by mouldy fungi such as Aspergillus, which produce aflatoxin, a toxic by-product extremely poisonous to people and which can lead to liver cancer.

African Maize Stalkborer in stem

Symptoms:

Young plants show small holes and 'window-panes' in the leaf whorls where tissues have been eaten away. Small dark caterpillars may be seen in the funnel. In severe attacks the central leaves die, forming the characteristic dry, withered 'dead-heart'.

Symptoms in maize plant include dead heart, plant death, dieback, internal feeding and presence of frass (insect faeces) in the stems. Older caterpillars tunnel in stems and eat out long frass-filled galleries, which weaken stems and cause breakages.

Early warning signs in maize: Small holes in straight lines on the youngest leaves.

African Maize Stalkborer feeding

African Maize Stalkborer damage

Affected Plant Stages

Flowering stage vegetative growing stage and generative stage

Affected Plant Parts

Growing points, inflorescence, leaves, seeds, grain, ear/head, stems

Symptoms by affected plant part

Growing points: Internal feeding; boring; external feeding; dead-heart; frass visible
Inflorescence: Abnormal colour; internal feeding; frass visible
Leaves: external feeding; frass visible
Seeds: Frass visible; empty grains
Stems: Abnormal growth; internal feeding; dead-heart; visible frass
Whole plant: Dead-heart; plant dead; dieback; internal feeding; frass visible

3.6.10.4. Cultural practices to prevent its occurrence

Monitoring

Scouting and early control is essential for effective management of stemborers. Check the crop regularly. First signs of a stalkborer attack are small holes or 'window panes' in straight lines across the newest leaves of maize or sorghum.

Field sanitation

Destroy crop residues

This is important to kill the pupae left in old stems and stubble and to prevent carry-over populations. It also limits the initial establishment of the pest on the following season's crops.

Plough and harrow

These practices help reduce borer populations by burying them deeply into the soil or by breaking the stems and exposing the caterpillars to natural enemies and to adverse weather conditions. Slashing maize and sorghum stubble, complemented with cultivation by disking and ploughing can reduce larval populations by almost 100% (Kfir *et al.*, 2002).

Burning crop residues is an effective way of killing stemborer caterpillars, but can create problems in farms where the organic content of soils is low and soil erosion is severe, as in many cases, crop residues are the only organic matter added into soils on smallholder farms. Alternative ways are needed to destroy diapausing caterpillars without destroying the stems in areas where stems of cereals are used as building and fencing materials, fuel, bedding for livestock or as stakes. In this case, partial burning is recommended, while the leaves are dry but the stalks are still green. Heat generated from the burning leaves kills up to 95% of stemborer caterpillars within the stems and at the same time cures the stalks, improving their quality as building materials and making them more resistant to termite attack.

Using crop residues for fodder and silage has also been recommended (CABI, 2000; Kfir *et al.*, 2002).

Destroying wild sorghum, which could act as alternative host, may help to reduce population upsurge.

For these cultural measures to be effective, the cooperation of farmers in a region is required because moths emerging from untreated fields can infest adjacent crops.

Improvement of soil fertility

Maintaining soil fertility that increases nitrogen use in maize production is important for the management of the African stalkborer. In studies in Cameroon, applying nitrogen to the soil improved the nutritional status of maize, which consequently enhanced its tolerance to the African maize stemborer attack (Chabi-Olaye *et al.*, 2008). However, if nitrogen is applied at rates greater than required for maximum yield, plant biomass increases at the expense of yield.

Technologies to restore soil fertility include cereal-legume rotations, use of farmyard manure and green manure cover crops. Legume cultivation and rotation are highly efficient in improving the supply of nitrogen in the soil.

Crop rotation

Maize-legume rotation sequences improve the supply of nitrogen in the soil and the nutritional status of maize, compared with maize-maize sequences. This influences the maize susceptibility to pests and diseases. The use of short duration fallows with leguminous cover crops and grain legumes have been useful in reducing yield losses due to borers in the subsequent crop. Rotation with grain legumes (cowpea and soybean) or leguminous cover crop pigeon pea and mucuna *(Mucuna pririens)* improved the supply of nitrogen in the soil and enhanced the yield of the subsequent maize crop in the humid forest of Cameroon. An improved nutritional status of the plant led to an increase in attacks by the African stalkborer at the early stages of the plant growth, but also improved plant vigour, resulting finally in a net benefit for the plant and grain yield (Chabby-Olaye *et al.*, 2005).

Intercropping and habitat management

The importance of plant biodiversity in maize agro-ecosystems for reducing borer's infestation on maize has been recognised in sub-Sahara Africa.

Maize intercropped with non-host crops (e.g. cassava and grain legumes) have significantly lowered stemborer damage and had higher yield than mono-crop maize. The effect is variable if the crop to be protected is not planted after the companion crops. In studies in Cameroon, maize mono-crops had 3 to 9 times more stems tunneled and 1 to 3 times more cob damage than maize intercropped with non-host crops such as cowpea, cassava and soybean, which resulted in a higher yield in the intercropped maize.

In the mixed cropping system, maize was planted 12 to 14 days after the non-host plants. Two plant arrangements were used:

One maize plant was followed by a non-host plant; and
Strip planting in which two rows of maize were followed by two rows of a non-host crop and with one row of non-host plants as borders

Maize yield losses due to stemborers were about 2 to 3 times higher in mono-crops than in intercrops. In addition, land-productivity was higher than with mono-crops. The maize-cassava intercrop was the most effective in terms of land use and more productive compared with pure maize stand with pesticide application. The net production of mixed cropping systems was economically superior to controlling stemborers with insecticide in mono-cropped maize (Chabi-Olaye *et al.*, 2005; Chabi-Olaye *et al.*, 2006).

Studies in Kenya suggested that intercropping maize and/or sorghum with cowpeas reduced damage caused by the African stalkborer (Amoako-Atta and Omolo, 1983; Reddy and Masyanga, 1988). Trials in Eritrea showed that sorghum intercropped with haricot beans, cowpea, *desmodium* and *Dolichos lablab* had much lower dead-heart damage compared with pure stand sorghum (ICIPE, 2005).

'Push-Pull Strategy'

Push-Pull is a simple cropping strategy, whereby farmers use Napier grass and *Desmodium* legume (silverleaf and greenleaf *Desmodium*) as intercrops. A detailed description of the strategy can be found at the beginning of the chapter.

Farmer practices

Application of baits at first signs of stalkborer attack (small holes in straight lines across the newest leaves of maize or sorghum) – one pinch per affected plant applied inside the funnel of maize plants.

Examples of bait: Maize flour or bran mixed with pyrethrum extract reportedly provides good control.

Scouting and early control is essential for this method to have any effect.

Caution: Application of too much bait inside maize and sorghum funnels can kill the growing point – a pinch of bait per plant is enough.

3.6.10.5. Remedies

Biological pest control

Natural enemies

Many natural enemies of the African stalk borer have been recorded in Africa. The most important are predatory ants, parasitic wasps and parasitic flies. Parasitic wasps may attack eggs *(e.g. Trichogramma spp. and Telenomus spp.)* or caterpillars *(e.g. Bracon spp and Cotesia sesamiae)*. Tachinid flies parasitise caterpillars. *Cotesia sesamiae* is the most common larval parasitoid (attacks caterpillars) of this stemborer on maize in eastern Africa.

Bio-pesticides and physical methods

Neem

Simple neem products are reported to be effective for control of stemborers, including the African maize stalkborer. It is recommended that a small amount of neem powder (ground neem seeds) mixed with dry clay or sawdust at a rate of 1:1 be placed in the funnel of the plant. One kg of powder should be sufficient to treat 1 500 to 2 000 plants. Using this method, rainwater dissolves the active substances in neem powder as it gathers in the funnel and washes out the powder. Where rainfall is irregular, a liquid neem seed extract can be sprayed into the funnel.

The treatment should be repeated every 8 to 10 days during the sensitive growing phase. Roughly three treatments are required per crop. This recommendation applies only for young plants before flowering and not for older plants. Neem powder should always be applied as a mixture with inert materials (sawdust, rice hulls or dry fine clay), as the powder alone can be phytotoxic (harmful to the plants) owing to its oil content (Dreyer, 1986).

In studies in Tanzania, aqueous seed extracts combined with extracted ground neem seeds and sawdust, applied twice to the whorl of maize leaves was as effective in controlling the African stalkborer as endosulfan. The extract was prepared by soaking 120g of neem seeds and 120g of sawdust in three litres of water for 12 hours. The mixture was filtered and the residue and the aqueous extract were then applied separately to the maize plants (Hellpap, 1995).

3.6.11. African armyworm

3.6.11.1. Scientific and common names

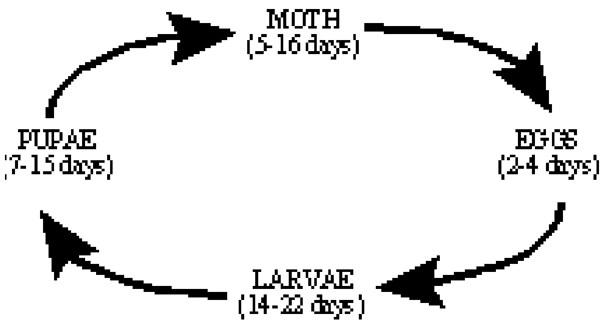
Spodoptera exempta, Laphygma exempta
Mystery worm, Barnosay

3.6.11.2. What it is

The African armyworm is a migratory moth; the larvae (caterpillars) are significant pests in pastures and cereal crops. They are predominantly in Africa, south of the Sahara, Yemen and some countries of the Pacific region.

Lifecycle of armyworm: 10 to 300 eggs are laid on the leaves by an adult female moth. The eggs are white and become dark brown just before hatching (about 0.5mm in diameter). Depending on temperature the eggs hatch after 2 to 5 days.

In East Africa the lifecycle lasts about 25 days at an average temperature of 26°C. Eggs hatch in 2 to 5 days; larval stage lasts 14 to 22 days; pupal phase takes 7 to 15 days; and adults lifespan is 5 to 16 days.



African army worm life cycle

Individual eggs are almost spherical, slightly flattened and about 0.5mm in diameter. They are whitish yellow in colour when newly laid, but darken just before hatching.

Female moths lay eggs at night in batches of 10 to 300 eggs in one or more layers on the leaves of the host plants, or sometimes on other surfaces such as dry grasses, leaves of tall plants, twigs of bushes and trees, or on buildings. The egg mass is covered with black hairs from the female. The eggs hatch after 2 to 5 days, depending on temperature.

Caterpillars occur in two principle forms; the gregarious form characteristic of high-density populations and the solitary form found at low caterpillar densities. They have a marked colour variation depending on density. Young caterpillars are green. Crowding of caterpillars results in changes in both their colour and behaviour, creating what appears to the untrained eye, to be two different species.

Normally, only small numbers of this pest occur, usually on pastures. However,

Army worm

periodically the populations increase dramatically and mass migration of moths occur, covering many thousands of square kilometres and traversing international boundaries. They travel from field to field in great numbers, hence the name "armyworm".

Outbreaks follow the onset of wet seasons, when dry grasslands produce new growth and cereal crops are planted. The severity and extent of outbreaks are increased by extended drought followed by early season rainstorms, which concentrate egg-laying moths and provide flushes of new grass as food for newly hatched caterpillars and dry and sunny periods during the caterpillar development, which promote survival and rapid development. Therefore, major upsurges occur in seasons of sporadic rainstorms and long sunny periods throughout the outbreak period.

Caterpillars are major pests in outbreak years, causing significant losses on a local, national and regional scale. During outbreaks, caterpillars occur in such high numbers that they have to travel in masses from one field to another in search of food to complete their development, devastating crops as they move. Significant losses are most consistently reported from southern and East Africa. However, in recent decades, the frequency of reports from West Africa has increased, possibly due to the extension of suitable grassland habitats following forest and bush clearance for agriculture.

The negative economic impact of the African armyworm is due to its rapid development (short life cycle), high reproductive capacity and mobility by migration. Moreover, there is little time to react as infestations frequently go unnoticed, since young caterpillars are difficult to detect. When caterpillars become conspicuous (at the fourth instar), they cause a lot of damage in a very short time.

The plants attacked are mainly cereals, grasses and sedges (Poaceae and Cyperaceae families). Major economically important hosts are: barley, pearl millet, African millet, maize, oats, rice, sorghum, sugarcane, teff, wheat and pasture grasses, especially Cynodon and Pennisetum species. Caterpillars exhibit strong host preferences within the Poaceae (cereals and grasses); there are major differences between varieties of cereal crops in their susceptibility to attack. Armyworm has once been found causing serious damage to coconut seedlings and once to young tea plants. During high-density outbreaks, non-host plants including tobacco and cotton may be eaten, though not extensively.

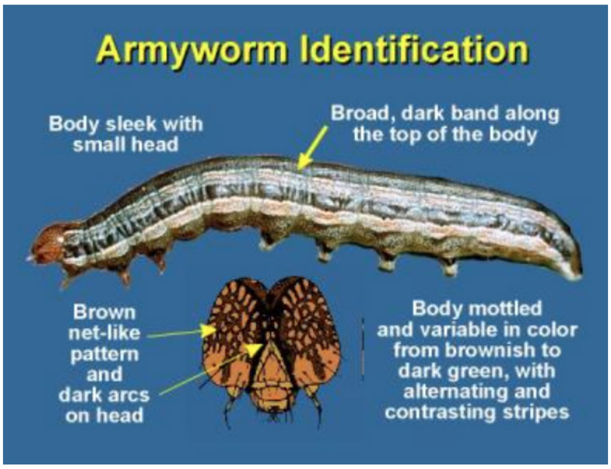
Primary hosts: *Sorghum bicolor* (sorghum), *Saccharum officinarum* (sugarcane), *Panicum miliaceum* (millet), *Oryza sativa* (rice), *Eragrostis tef* (teff), *Zea mays* (maize), *Hordeum vulgare* (barley), *Avena sativa* (oats), *Triticum spp.* (wheat) and *Zingiber officinale* (ginger).

Secondary hosts: *Palmae* (plants of the palm family), *Rosaceae, Cyperus* (flatsedge).

Wild hosts: *Eleusine coracana* (Koracan), *Poaceae* (grasses), *Cyperaceae* (Sedges), *Cynodon dactylon* (Bermuda grass), *Panicum maximum* (Guinea grass), *Pennisetum clandestinum* (Kikuyu grass), *Cynodon spp.* (Quickgrass) and *Pennisetum glaucum* (Pearl millet).

Young caterpillars are green.

Gregarious caterpillars (caterpillars that live communally) become blackish as they grow. Fully-grown caterpillars are about 40mm in length; they are velvety-black on the upper body surface with green, black, yellow and white lateral stripes. The underside of the body is green or yellow and the larvae do not have hairs on the body. The head is shiny-black.



Army worm identification

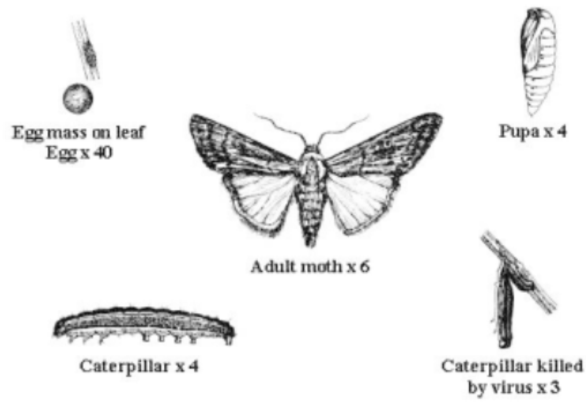
Gregarious caterpillars are very active and feed on the upper part of the plant, avoiding shade.

Solitary caterpillars (caterpillars growing singly) are coloured in a variety of shades of green-brown or pink, with a pale speckled head. They appear fat and are extremely sluggish, actively avoid the sun and feed at the base of grasses.

Armyworm caterpillars usually feed on cloudy days and at night. When armyworms are numerous and the food supply becomes depleted, caterpillars march in great numbers to find a new food source. During this time they may also be seen feeding during the day. Mature caterpillars burrow into the soil to pupate.

The pupae are brown in colour right after pupation turning darker brown and finally almost black. They are 10mm to 14mm long, with a smooth, shiny surface and are enclosed in a delicate cocoon of soil particles held together by silk.

Adult African armyworms are stout-bodied moths, 1.4cm to 1.8cm long and with a wingspan of about 3cm. Forewings are dark-brown with distinctive grey-black markings. Hindwings are white with dark veins.



Army worm life stages

Army worm moth

Life stages of beet armyworm
(Spodoptera exigua)
A related species, *Spodoptera exigua* (Lesser armyworm or beet armyworm) feeds not only on *Gramineae* but also on many other crops, including cotton, tobacco, tomato, groundnut and beans. Unlike *S. exempta*, this species

does not migrate over long distances, but the caterpillars are gregarious and move in swarms. They are about 1.2 cm long with a wingspan of 2.5 cm. They are light grey with a small, round, light orange spot and a small, kidney-shaped spot on the forewing. Newly hatched caterpillars are light green with black heads. The fully grown caterpillars are about 3 cm long, light green to dark brown with conspicuous stripes along the sides of the body.

A female moth can lay 500 to 600 eggs, in clusters of between 50 and 150, is covered with scales and hairs, which gives a woolly appearance. Eggs are greenish cream coloured when freshly laid turning dark in colour before hatching. The eggs hatch after 2 to 4 days depending on temperature. Newly hatched caterpillars are about 1 mm long, light green in colour with black heads. Young larvae feed on the underside of leaves, causing characteristic 'windowing'. The fully-grown caterpillar is about 30mm long, light green with conspicuous stripes along the sides of the body. The average larval period is about 11 days. The larvae pupate in the soil and the adult moth emerges after about six days.

3.6.11.3. The damage caused

The degree of damage to crops depends on:

Stage of development of the crop
Prevailing weather conditions
Density of caterpillars present and area affected

In areas with high and localised rainfall during armyworm seasons, plants can regenerate, provided the growing tips are not damaged, with little or no yield reduction. In contrast, in areas of erratic rainfall, farmers may lose their crop completely.

The degree of damage by armyworms varies from year to year. In East Africa, a severe outbreak can cover several square kilometres at very high densities, while in non-outbreak years, caterpillar density is often low and the size of attacked areas is negligible. Armyworm outbreaks in Tanzania and Kenya are serious in nine years out of ten, causing up to 90% losses of crops and pasture in bad years. They destroyed 157,000 hectares of crops and pasture in 2001. In major outbreak years, the moths migrate to cause extensive damage in Uganda, Ethiopia, Somalia and Eritrea and may travel as far as Yemen, and south to Malawi, Mozambique and Zambia. Grasslands, even maturing crops can be totally destroyed. If drought conditions follow an outbreak, plants may not recover from defoliation and replanting may fail to produce a crop.

The damage to cereal crops results principally from attack on young plants by young caterpillars hatching or dispersing into the crop from adjacent wild grasses. Weed-free maize crops taller than 50cm are unlikely to become infested by newly hatched caterpillars because the leaves are too tough to allow them to establish. However, when older caterpillars moving from heavily infested grasslands invade fields, even maturing crops can be totally destroyed. Reported yield losses caused by defoliation in maize range from 9% in plants attacked at the early whorl (four leaves) stage to 100% in those damaged at the pre-tassel stage. The ability of young maize plants to recover from armyworm damage depends on the position of the growing point at the time of attack and the amount of root development when the caterpillars stop feeding. Damage is always serious if the growing point is affected but, as it remains at the base of the plant until near the pre-tassel stage, it may be below ground during the outbreak and remain undamaged.

Replanting maize after armyworms have destroyed the first-sown plants is frequently unsatisfactory, as the optimum planting dates will have been missed. Yield losses of 6%

have been estimated for each day's delay after the optimum planting date in high-rainfall areas in Kenya. Late planting may result in much higher losses in areas with less rainfall; yield losses of up to 92% have been recorded in such areas in Malawi and Kenya. If drought conditions follow an outbreak, plants may not recover from defoliation and replanting may fail to produce a crop.

In sorghum, millet, rice and teff, armyworm damage may stimulate growth of tillers (lateral shoots on or just under the surface of the ground), which can increase yield in favourable conditions. If subsequent rainfall is adequate for crop growth and development, yield losses may be limited, provided the damage occurs before the critical grain-initiation stage has been reached.

Damage to pasture and rangeland can be extensive and severe. Good rainfall after infestation is an important factor in pasture recovery. In Kenya, vegetation changes in infested pastures have been reported to persist for many years before good grass cover has been restored by management of dicotyledonous weeds.

Indirect losses of livestock due to armyworm outbreaks in pastures are sometimes severe, due to a combination of starvation and poisoning. The latter occurs when cattle graze on pastures recently infested with armyworm. Deaths among cattle grazing recently infested pasture have been reported by herdsmen in southern Ethiopia, Somalia (where 100 cattle were reported to have died on one occasion) and Kenya, as well as in southern Africa. Speculations as to the causes of death include high cyanide levels induced in Cynodon grasses by armyworm damage and ingestion of caterpillars or fungal mycotoxins on armyworm faeces.

Symptoms of African armyworm attack are gross feeding damage to foliage, growing points and young stems. Young caterpillars scrape out the tissue of one side of the leaves creating a 'window' effect; leaves may dry up and assume a scorched appearance. Older caterpillars feed on leaves starting at the margins and move inwards, leaving the leaves with a ragged appearance. They may eat whole leaves leaving only the midrib.

Army worm damage on sorghum

Severe infestation results in total defoliation or destruction of the plant to ground level. Older caterpillars drop to the ground if disturbed. With large populations the ground may be literally covered with the gregarious band of caterpillars.

Affected Plant Stages

Flowering stage, fruiting stage, seedling stage and vegetative growing stage

Affected Plant Parts

Growing points, leaves and stems

Symptoms by affected plant part

Growing points: External feeding
Leaves: External feeding, windowing, ragged leaves
Stems: External feeding

3.6.11.4. Cultural practices to prevent its occurrence

Monitoring

To monitor the presence of armyworm, conduct visual inspections by going around all your fields. Armyworms feed at night and hide under debris during the day. Solitary forms are usually sparsely distributed and difficult to find. Consequently, armyworms are not usually noticed until severe damage occurs.

However, they can be monitored late in the evening or early morning as they may still be actively feeding. Some caterpillars may be seen feeding on overcast days, especially during a severe outbreak. Hand-pick the caterpillars and feed these to chickens and ducks.

Regular monitoring is vital for timely action. Look in field margins, low areas where plants have lodged, beneath plant debris around the base of plants, on the ground and underneath plant leaves.

If conditions are favourable for the pest, a close watch should be kept daily on grassland and young cereal crops. The earlier the infestation is noticed, the more effectively control methods be implemented.

A recommendation for monitoring armyworms is to examine 100 plants at random by selecting 20 plants from five locations.

Tentative nominal action thresholds for control measures have been determined for maize. To avoid yield losses of over 15%, action thresholds for early whorl maize should be taken as 200 second (L2), 80 third (L3), or 20 fourth (L4) instar caterpillars per 100 plants. Serious damage develops rapidly once caterpillars reach the L4 stage (CABI, 2000). As a general rule, control measures for the protection of pasture are not recommended unless caterpillar densities exceed 10m^2 (CABI, 2000).

Control of armyworms is a large-scale venture and requires international collaboration. It usually involves early warning based on light traps or pheromone catchers, or forecasts based on prevailing meteorological conditions. Accurate monitoring and prompt reporting of armyworm outbreaks is essential for forecasting and control.

A forecasting system for armyworms has been in operation in East Africa since 1969. National crop protection services have departments such as the Plant Protection Services in Tanzania and the Crop Protection Branch in Kenya with special responsibility for the control of migrant pests, including armyworm. In Tanzania, the National Armyworm Control Programme based at Tengeru-Arusha, runs a network of traps distributed throughout the country. Farmers are advised to inspect their fields for signs of infestation immediately after the forecast warns of expected outbreak in the area. Recently, a community-based monitoring system has been implemented successfully in several high-risk districts, where armyworm forecasters have been trained to monitor male moth numbers through the use of pheromone traps (Mushobozi et al., 2005).

Lancaster University in the UK provides a free website service to forecast army worm outbreaks in Southern Africa: *http://www.lancaster.ac.uk/armyworm*

The Desert Locust Control Organization for Eastern Africa (DLCO-EA) and the International Red Locust Control Organization for Central and Southern Africa (IRLCO-CSA) have regional responsibilities for armyworm.

Armyworm attacks are notifiable in the region. This means that if anyone spots armyworms, it should be reported immediately to the authorities (Ministry of Agriculture/National Crop Protection Services), which will then send an eradication team, depending on the severity of the outbreak.

Listen to radio announcements to prepare yourself for armyworm outbreaks.

FAO (*http://www.fao.org/emergencies*) has an emergency Twitter update for army worm – *https://twitter.com/hashtag/Armyworm?src=hash*

Field sanitation
Cut grass weeds from bordering fields. Remove weeds regularly to reduce breeding sites and shelter for armyworm. However, if fields do become infested leaving grass weeds until the caterpillars have pupated or been controlled may help to reduce damage to the crop, since caterpillars may feed on weeds. Remove all plant debris after harvesting.

Variety selection
Some maize varieties are more susceptible to attack than others. These varieties are most at risk where probabilities of armyworm infestation are high.

Tillage
Plough and harrow field thoroughly. Turning the soil exposes armyworm pupae to desiccation and natural enemies.

Habitat management
Avoid burning and overgrazing of grasslands, which are the natural habitat and food store for the caterpillars. Burning often causes outbreaks because as soon as temperatures rise, eggs are laid in large quantities on the fresh new grass. No oviposition occurs at temperatures lower than 20°C. Also, if their natural habitat and food is unavailable they will attack other crops (HDRA).

An outbreak is more likely to occur if crops have been fertilised with high quantities of nitrogen as this causes green, sappy growth, which is very attractive to armyworm caterpillars.

3.6.11.5. Remedies

Biological pest control

Natural enemies

Natural enemies should be encouraged by maintaining natural surroundings including trees and shrubs with plenty of breeding places.

Many birds, toads, lizards, small mammals, insects and spiders prey on the African armyworm at different stages of its life cycle.

Lacewings, predatory wasps, parasitic wasps, flies and spiders attack armyworm caterpillars. Night birds and bats feed on the African armyworm moths.

Birds (storks and crows) may decimate small outbreaks but have little influence on larger ones.

Viruses and fungi
Armyworms are also attacked by viruses and fungi. In some instances, viruses have been known to cause armyworm populations to crash within a few days. Armyworm caterpillars infected with a virus appear limp and hang from plants after they die.

The Nuclear Polyhedrosis Virus used specifically for the African armyworm *(SpexNPV)*, sometimes acts as a natural control during a caterpillar outbreak. The first armyworm outbreaks of the season may be virus-free, but this virus could eliminate later outbreaks, with mortalities of over 98% being the norm. Widespread virus attack is often associated with overcast, cool, wet weather.

The main problem with NPV is that it generally spreads too slowly and it arrives too late to prevent crop loss. However, NPV can be sprayed like other pesticides and once sprayed; the virus spreads and multiplies in the armyworm. To be effective, NPV has to be sprayed on to very young caterpillars, ideally in the first few days after hatching, so it is vital that information about outbreaks is gathered quickly. This requires early warning of outbreaks, through regular monitoring of moth numbers. A joint project to develop alternative, non-chemical technologies for the management of the African armyworm between the Tanzanian government and the UK's Natural Resources Institute (NRI) was initiated in Tanzania in 1999. The project has developed a system to mass-produce NPV cheaply as well as a community-based armyworm forecasting pack, which also provides decision making tools (Earth report 6, Mushobozi et al, 2005; New Agriculturist, 2006). Information on the product is available on *www.dfid.gov.uk.*

Another virus *(Cytoplasmic Virus)* is also an important pathogen, killing pre-pupae and pupae.

Fungi and bacteria are thought to be of minor importance (Odiyo and Stickler, 1977; Rose *et al*., 1996).

It is a known fact that armyworms are attacked in nature by viruses *e.g. Spodoptera exemptanuclear polyhedrosis virus (SpexNPV)* and *Cytoplasmic virus*. Field trials prove that *SpexNPV* sprays at the rate of 1 x 10^{12} occlusion bodies per hectare are effective in controlling armyworms. Sprays were applied at the third instar stage.

Bio-pesticides and physical methods

Bio-pesticides

Bio-pesticides (including botanicals/plant extracts and microbials) such as Neem, Pyrethrum and *Bt* should be applied if larvae are at or above threshold levels and preferably when caterpillars are approximately 12mm to 20mm long before most damage has occurred. Once caterpillars are mature, or are between 30mm and 35mm long, they will have done most of their feeding damage and it would no longer be economical to apply a bio-pesticide. In Namibia, the quoted threshold is 25 armyworms per trap. Traps are checked weekly (Namibian Crop Pests No. 28).

Bio-pesticides should be applied in the evening since armyworms prefer to feed at night.

Precautions: It is important to follow all precautions and directions listed on the label when using a commercial bio-pesticide (or a pesticide) and ensure that the product is registered for armyworms on the specified crop. Pay particular attention to the required water volume to be used. Best control is achieved when using the highest water volumes. This applies to pesticide and bio-pesticide use for all pests/crops.

Neem

Trials carried out in Tanzania showed that both neem seed and leaf extracts could be used to kill armyworms. Even though neem extracts are as effective as SpexNPV and synthetic pesticides, their use is only practical on small holdings. The high bulk of neem needed and high transport costs means it is not feasible to use on a large scale.

How to prepare neem solution:

- Fallen neem fruits are collected from beneath the trees. The flesh is removed from the seeds and any remaining shreds washed away. The seed is carefully dried in airy conditions (in sacks or baskets) to avoid mould formation. When needed, the seeds are shelled, finely grated and then soaked overnight in a cloth suspended in a barrel of water. Dosage: 50g of neem

powder per litre of water. This solution is then sprayed on infested plants
- Grind 500g of neem seed kernels in a mill or pound in a mortar
- Mix the crushed neem seed with 10 litres of water. It is necessary to use a lot of water because the active ingredients do not dissolve easily. Stir the mixture well.
- Leave to stand for at least 5 hours in a shaded area
- Spray the neem water directly onto the crop using a sprayer or straw brush

About 20kg to 30kg of neem seeds (an average yield from 2 trees), prepared as neem water can treat one hectare of crop.

Neem water can be stored and will remain effective for 3 to 6 days if it is kept in the dark.

Pyrethrum

Pyrethrum liquid:
- Mix 20g pyrethrum powder with 10 litres water. Soap can be added to make the substance more effective but it is not vital. Apply immediately as a spray

Bt (Bacillus thuringiensis)

How to use Bt:
- Spray thoroughly, covering all the plant surfaces
- Apply when larvae are less than 5mm long or when the eggs begin to hatch. Bt works best on young larvae
- In the tropics, it is more effective to spray Bt in the late afternoon as there are longer and cooler hours ahead. This enables Bt to remain on the surface of leaves for longer. Bt survives better in cooler temperatures. Whereas spraying in the morning provides a shorter and hotter environment
- Do not mix the Bt concentrate with alkaline water (pH 8 or higher). Alkalinity reduces its effectiveness. To make the water acidic, add a few tablespoons of white vinegar in a gallon of water before adding Bt.

Physical methods

There are different physical methods that are practiced mainly on small holdings:
- Plough a deep ditch. Keep it filled with water. This method is helpful when caterpillars are found to be moving towards your field from adjacent fields
- Another method is to dig a deep ditch with vertical sides to trap the caterpillars and prevent them from crawling out. Dig a hole the size of a fence post in diameter every 10 meters within the ditch. Caterpillars are lured to congregate in the holes. Collect and properly dispose of the trapped caterpillars
- Use light traps. They can provide useful information about the population of moths and therefore of caterpillars. Light traps help to predict if there is going to be an outbreak. However, light traps attract many other insects, including other moths. Therefore, it is very important to be able to recognise moths of the African armyworm. The use of light traps is primarily a monitoring tool
- A wooden tripod with a kerosene lantern is a locally improvised ''light trap''. A tripod made of wooden poles (bamboo) is constructed with a lantern (kerosene) hanging in the middle over a bowl of water. The lantern is a fire hazard so the tripod must be secure and the lamp must be hung so that the wood does not catch fire
- Hand picking of caterpillars. This is only feasible on very small plots

3.6.12. Banana weevil

3.6.12.1. Scientific and common names

Cosmopolites sordidus
Banana weevil borer, banana root weevil, banana root borer, banana rhizome weevil, banana borer, plantain weevil, corm weevil, banana beetle

3.6.12.2. What it is

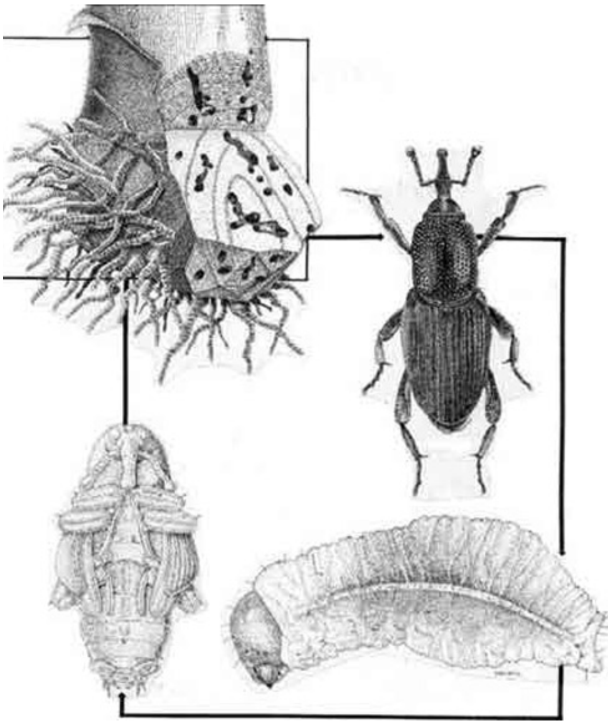
Banana weevil is a pest of banana, plantain *(Musa spp.)* and ensete *(Ensete spp.)*. Weevil problems appear to be most severe in plantains, highland cooking bananas and ensete. The weevil has contributed to the decline and disappearance of highland cooking banana in parts of East Africa. Weevil pest status in other groups of bananas is variable. In commercial Cavendish plantations, the banana weevil has been reported to be relatively harmless (Gold and Messiaen, 2000).

The eggs are elongate-oval, about 2mm to 3mm long and white in colour. Eggs are laid singly in small cavities that are chewed out by the female in the base of the pseudostem just above ground level, in the upper part of the corm, in roots near the soil surface and at the end of cut stems (stumps). Due to their white colour they are rarely seen in the corm tissue. The duration of the egg stage is varies (4 to 36 days) depending on temperature. Hatching takes place after 6 to 8 days in tropical conditions.

The larvae (grubs) are creamy white legless grubs, stout and distinctly curved and swollen in the middle of the body. The head is reddish-brown with strong mouthparts. Fully-grown grubs are about 12mm long. Under tropical conditions, the larvae complete their development and pupate in 20 to 25 days.

Pupae are white and about 12mm long. Pupation takes place in holes bored by the grubs. As it develops, the shape of the adult becomes visible. Adults emerge from the pupae 5 to 7 days after pupation.

Banana weevil grub



Banana weevil life cycle

Banana weevil pupa

Adults are 10 to16 mm long weevils (snout beetles), hard-shelled, with a rather long curved snout. Newly emerged weevils are red brown, turning almost black after a few days. They are most commonly found between leaf sheaths, in the soil at the base of the mat or associated with crop residues. They often remain within the plant before biting the external sheath and leaving the banana plant. They feed on dead banana plants, newly cut stems and other decaying plant material near the base of banana plants. Weevils may live for up to 2 years and can live without food for 6 months, but are very sensitive to desiccation and will die within 48 hours if kept in a dry substrate. They are active at night. The adults are sluggish and rarely fly, but walk over the soil surface and vegetation and feign death when disturbed. Adults are not strong flyers and only cover short distances.

Banana weevil adults

Infestation by the banana weevil begins at the base of the outermost leaf-sheath and in injured tissues at the lower part of the pseudostem. Initially the young grubs make several longitudinal tunnels in the surface tissue until they are able to penetrate to adjacent inner leaf-sheaths. They then bore into the pseudostem base and rhizome/corm, into the base of suckers and into the roots. Larval tunnels may run for the entire length of fallen pseudostems. Infested plants have dull yellow green and floppy foliage. Young infested suckers often wither and fail to develop. Plants are easily blown down by mild to strong winds.

3.6.12.3. The damage caused

Grubs feed by making irregular tunnels in the corm and rootstock. Tunnels are roughly circular and can reach up to about 8mm in diameter. The corm can be riddled with tunnels, which promotes fungal infection and decay, reducing it to a black mass of rotten tissue. Injury to the corm can interfere with root initiation and sap flow in the plant. As a result, the leaves turn yellow, wither and die prematurely. Young suckers show symptoms of wilting and die, while older plants are retarded in their growth. Heavily infested plants produce small bunches of leaves and are easily blown over by the wind. Spent stems, cut or standing, are attacked rapidly.

Banana weevil damage - Oswaldo Brito, Independent Consultant, Bugwood.org

Damage is worst in neglected plants. In fertile soils and with good crop husbandry it is seldom serious. Banana weevil numbers are often low in newly planted fields. Population build-up is slow and weevil problems are most often encountered in ratoon crops. The banana weevil damage is more serious in low altitude areas than in highland areas as a result of temperature. Weevils are usually not a problem beyond 1 500m above sea level (Karubaga and Kimaru, 1999; Gold and Messiaen, 2000).

Affected plant stages

Flowering stage, fruiting stage, seedling stage and vegetative growing stage

Affected plant parts

Roots and stems

Symptoms by affected plant part

Roots: internal feeding
Stems: internal feeding

3.6.12.4. Cultural practices to prevent its occurrence

Cultural practices

Use clean planting material. Planting infested rhizomes/corm and suckers increases damage.

This can be done by:

- Selecting vigorous healthy planting material obtained from plants free of weevils. Examine planting material by taking one or two slices from it. If grubs, pupae or tunnels are present, the material should be destroyed
- Paring (trimming). If clean planting material is not available, the planting material should be pared (trimmed) to reduce the number of eggs and grubs. However, badly damaged suckers should not be used for planting. Paring allows for superficial inspection of the rhizome surface and rejection of suckers containing weevil damage. However, significant internal damage may be present on suckers in which the rhizome displays little evidence of attack. Paring and removal of outer leaf sheaths also helps to remove most weevil eggs and nematodes
- Hot water treatment. Recommendations suggest immersing clean trimmed suckers in a bath with hot water at 52° to 55°C for 15 to 27 minutes before planting. There have been reports of hot water treatment killing remaining eggs and a high percentage of grubs. For example, Gettman et al. (1992) reported over 99% mortality of weevil eggs and grubs when suckers of dessert bananas were placed in a water bath of 43°C for 3 hours However, other sources indicate that hot baths are very effective in eliminating nematodes, but kill only a third of the weevil grubs. Thus, hot water treatment of planting material is likely to provide protection against weevil for several crop cycles only (Gold and Messiaen, 2000)
- A simple method for farmers to control temperature has been developed in Kenya. It consists of a pith block (of about 3cm) or a small piece of wood tied to an iron plate (3 x 3cm and weighing about 10g) covered with a thin film of candle wax. This device is allowed to sink in a half-empty oil drum with water, in which the banana material to be treated is placed. Wood is burnt underneath the drum, when the temperature rises to 55°C the wax melts releasing the pith or piece of wood, which then floats to the surface. At this moment the firewood is removed (Prasad and Seshu Reddy, 1994).

Do not replant previously infested land while old corms remain on the ground, or where insufficient time has passed for adult weevils to die after remnants of the previous crop has been removed.

Clean planting material must be planted in a new plantation as soon as possible. It should not be left overnight in heaps because it could attract weevils and be re-infested before planting.

Harvesting of all mature pseudostems at certain intervals is suggested as a preventive measure of control. This discourages the continuous breeding of the weevil (CABI).

Avoid moving infested plant material from plantation to plantation as this will spread banana weevils.

Sanitation

Practice good crop hygiene:

- Cut old stems after harvesting at ground level. Covering the cut rhizome with a layer of soil is said to prevent the weevils from penetrating the corm and laying eggs
- Cut old stems as soon as the bunch is harvested as well as wind-damaged pseudostems (stumps) into small pieces and scatter them so that they quickly dry and do not attract the weevils. Alternatively, they can be cut into larger pieces and used for trapping weevils *(see page 113)*
- Dig out and remove old corms, trash and other materials in which weevils may breed

Practice good crop husbandry to produce vigorous banana plants, which are more able to tolerate weevil damage:

- Use mulch. Spread mulch away from banana stool leaving a clear ring of about 60cm from the base of the stool to keep the roots from growing towards the surface and to avoid moist conditions near the stool, which attracts banana weevils
- De-sucker and remove water suckers regularly
- Clean mats of dead leaves and plant debris
- Keep the plantation free of weeds at all times
- Ensure proper fertilisation. Application of manure is important in the early stages of growth of the banana plant

3.6.12.5. Remedies

Biological pest control

Natural enemies

Predatory ants such as the bigheaded ant *(Pheidole megacephala)* and *Tetramorium spp.* are important predators of the banana weevil. Although these ants are generalists, (they feed on a wide variety of food materials such as nectar, sugar, honeydew, other insect substances with high fat content, etc.) high populations in banana stands make them very efficient predators. They will enter crop residues and living plants in search of weevil eggs, grubs and pupae. These ants have reportedly contributed to the successful control of banana weevil in plantain in Cuba. These ants can be encouraged to nest in pseudostem pieces that can then be used for further distribution. They are widespread and may also be important predators on the weevil in other localities.

Studies in Tanzania and Uganda have shown that several species of ants are important natural enemies of the banana weevil in the region (Aberra, *et al.*, 2007; Varela, ICIPE, personal communication).

Some fungi *(e.g. Beauveria bassiana and Metarhizium anisopliae)* have shown efficacy as control agents of this pest. Some of them cause weevil mortality of over 90%. In Cuba, the fungus *Beauveria bassiana* is reported to be effective against the banana weevil in combination with ants (CABI, 2000). However, there is little information on the performance in field conditions. Moreover, the distribution and application of these biocontrol agents are still restricted by a lack of facilities and high costs.

Some nematodes, *(Steinerma and Heterorhabditis spp.)* attack both adults and grubs in the field, but financial cost and their efficacy limit their use on a large scale (Gold and Messiaen, 2000).

Bio-pesticides and physical methods

Neem (Azadirachta indica)

Applications of neem powder effectively controlled weevils and nematodes in on-farm trials and in farmer's fields in Kenya. Application of 60g to 100g of neem seed powder or neem cake at planting and then at 4 month intervals significantly diminished pest damage and increased yields. Application of over 100g or neem oil was phytotoxic (harmful to plants) and uneconomical.

Neem applications were economical in fertile soils with moderate pest infestation. Neem applications to banana plants grown in poor soil and under very high pest attack were uneconomical. A combination of application of cow dung and neem treatments resulted in yield increases of between 50% and 75% (Musabyimana, 1999). Dipping suckers in a 20% neem seed solution at planting protects the young suckers from weevil attack. This is achieved by repelling adult weevils that would lay eggs in the first place. Egg hatching rates could also be lowered in neem-treated plants (Gold and Messiaen, 2000).

Trapping

Disc-on-stump traps and old pseudostems can be used for trapping weevils. Disc-on-stump traps consist of corm slices placed on top of harvested plants, cut at the rhizome. Old pseudostems can be cut into lengths of 20cm to 60cm, split lengthwise and placed on the ground near the corm bases with the cut surface facing downwards. Adult weevils are attracted to the cut stems or corms for shelter, to feed and to lay eggs. When the eggs hatch, the life cycle cannot continue as the cut pieces dry out and the grubs die from desiccation. The weevils can be collected by hand and destroyed. The efficiency of the traps depends on their numbers and the frequency of trapping. Disk-on-stump traps collect 3 to 7 times as many weevils as pseudostem traps.

3.6.13. Cabbage looper

3.6.13.1. Scientific and common names

Trichoplusia ni
Semi-looper, cabbage semilooper

3.6.13.2. What it is

The cabbage looper is widely distributed in the tropics and subtropics. It is a serious pest of cruciferous crops, but it also attacks other important crops such as tomato, lettuce, potatoes, sweet potatoes, cotton, cucurbits, etc. The cabbage looper is somewhat erratic in occurrence, is typically abundant one year and scarce for two to three years.

The eggs are round or slightly dome-shaped with ridges and about the size of a pinhead. They are pearly or silvery white and darken when they age. Eggs are usually laid singly on the undersides of leaves. A female moth can lay from 300 to 1 600 eggs. Caterpillars hatch in 2 to 6 days after the eggs were laid.

The caterpillars go through five instars during development. Very young caterpillars are white and almost clear with a black head capsule. Older caterpillars are green with a thin white line on each side just above the spiracles and two other white lines on the dorsum. Caterpillars have three pairs of legs near the head and three sets of prolegs (false legs) near its rear. They move in a "looping" manner, arching the middle portion of the body as they move forward. Fully-grown caterpillars reach 3cm to 4cm in length.

Cabbage looper feeding on a kale leaf

Cabbage looper

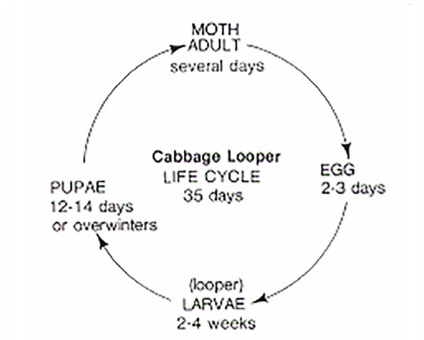
Caterpillars pupate in white loose cocoons attached to the underside of leaves, in a folded webbed leaf or between two webbed leaves. The pupae are light green when young and gradually turn dark brown when mature. The moths are light green when young and gradually turn dark brown when mature. The moths emerge from the pupae 10 to 16 days after pupation.

Cabbage looper pupa

The adult is a mottle, greyish-brown moth, about 2.5cm long and with a wingspan of 4cm. The front wings have two small silvery spots, one small and round, the other U-shaped (resembling an '8'), near the middle part of the wing. The hindwings are pale brown. Cabbage looper moths are strong fliers and are primarily nocturnal. During the day the moths can be found resting in foliage or in crop debris.

Cabbage looper moth

Development from egg to adult takes about 4 to 6 weeks.



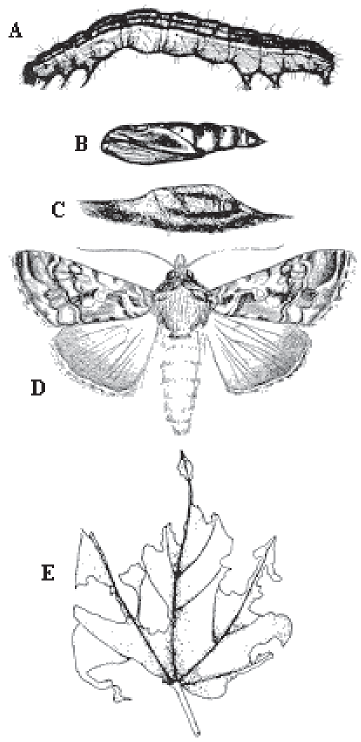
Cabbage looper life cycle

The cabbage looper has a wide host range that includes crucifers, beans, cotton and various vegetable crops. It is listed as feeding on over 160 species of plants in 36 families, but cultivated crucifers are preferred.

3.6.13.3. The damage caused

Symptoms

Caterpillars feed primarily on leaves and cause irregular holes. Young caterpillars eat small holes, but older caterpillars feed on the tissue between the veins skeletonising the leaves (leaving only the midribs and veins) or giving them a ragged appearance. Plants can be severely defoliated and stunted, producing no heads or becoming unfit for consumption. They may also bore into the heads of lettuce and cabbage, contaminating them with frass. The presence of caterpillars and contamination



Cabbage looper life stages

of marketable plant parts with frass reduces the market value of the produce. Large amounts of dark green pellets excreted by the feeding looper may stain cauliflower heads. The presence of cabbage looper caterpillars in broccoli heads renders them unmarketable.

Cabbage looper damage

Affected plant stages

Vegetative growing stage

Affected plant parts

Leaves and whole plant

Symptoms by affected plant part

Leaves: external feeding; internal feeding; webbing; frass visible; shredding.
Whole plant: plant death; dieback; dwarfing; internal feeding; external feeding; frass visible

3.6.13.4. Cultural practices to prevent its occurrence

Monitoring

Inspect plants regularly for the presence of caterpillars, leaf damage and the presence of frass. Caterpillars can be detected by scouting the crop, while adults can be monitored by using light or pheromone-baited traps.

Monitor the presence of natural enemies. They play an important role in controlling the cabbage looper. Check plants twice a week once seedling emergence begins. Check more often when populations appear to increase. Treatment thresholds vary depending on the crop and location. Normally, spraying should not occur when there is less than 1 caterpillar per 5 plants (CABI, 2000). A control measure is not necessary unless you find more than 9 small to medium-sized caterpillars per plant.

Management options

Plant resistant varieties, if available. Some resistant varieties are "Mammoth Red Rock", "Chieftan Savoy" and "Savoy Perfection Drumhead". Ask for assistance from local agriculture office to obtain cabbage looper resistant cultivars that are available in the local markets

Remove and destroy all the plant debris after harvest. The pupae might still be present in the plants. Plough and harrow the field after harvest
Clear the surrounding area of weeds, which may serve as alternative hosts for the pests

3.6.13.5. Remedies

Biological pest control

Natural enemies

Natural enemies usually keep the pest populations at low levels and control measures are not often needed. Therefore, their conservation is very important. Avoid using broad-spectrum pesticides for the control of this or other pests. Cabbage looper infestations often increase after use of broad-spectrum pesticides due to the elimination of natural enemies.

A wide range of natural enemies attacks the cabbage looper; predators, egg and larval parasitoids (parasitic wasps) and pathogens (Bt and viruses).

Egg predators and parasitoids are important since they kill eggs preventing any subsequent damage by caterpillars.

The *Nuclear Polyhedrosis Virus* is particularly important in controlling this pest. The virus occurs naturally in the soil or on plants in most crop areas. Virus-infected insects can be reintroduced into the field by collecting diseased insects, mixing them in a blender, filtering out large tissue masses and then spraying the virus particles back onto the field.

Bio-pesticides and physical methods

Bt (Bacillus thuringiensis)

Bt products give good control of the cabbage looper and do not harm natural enemies. For optimum control, treatments should be applied when caterpillars are small. Frequent crop monitoring is helpful to know the optimal time to apply Bt and other insecticides.

Neem

Neem-based pesticides are reported to control the cabbage looper by interfering with the growth of young caterpillars. Fairly good control of this pest has been obtained with a 2% ethanolic extract of neem seeds (Ostermann and Dreyer, 2000).

Physical control methods

- Handpick the caterpillars and egg masses
- Use fine nylon nets as row covers to protect seedlings from egg-laying moths

3.6.14. Cabbage moth

3.6.14.1. Scientific and common names

Crocidolomia pavonana (C. binotalis)
Cabbage moth, cabbage head caterpillar, larger cabbage webworm

3.6.14.2. What it is

The cabbage moth is common during dry, cool seasons in many tropical and subtropical regions.

Eggs have a brown furry appearance and are laid in batches on the lower surfaces of leaves usually close to the midrib or the veins and arranged like roof tiles in an overlapping manner. The colour of egg mass is green on the first day turning to reddish-brown after two or three days (at the time of hatching). A large egg mass is about 5mm in diameter. Each female lays 75 to 300 eggs. Smooth leaf surfaces are preferred for egg laying. Eggs hatch 4 to 7 days later.

Caterpillars are dark green with a light brown head and dark and yellowish-white light stripes along the body. These stripes are less visible when larvae are close to pupation. They measure 1.6cm to 2cm in length when fully grown. They go through five instars to pupate. Young caterpillars are often found in groups feeding near the egg mass. Older caterpillars disperse moving from plant to plant. Caterpillars actively feed for 10 to 18 days, descending into the soil to pupate.

Cabbage moth catepillars

The pupa is yellowish green when formed and turns dark brown later. Pupation takes place in a loose silken cocoon 2cm to 60cm below soil surface. Pupae are about 1cm long. Moths emerge from pupae 10 to 15 days after pupation.

Cabbage moth life stages

Adult moths are light brown with a wingspan of about 2cm. Adults emerge during the night. They are weak fliers live for about 8 days.

The cabbage moth is primarily a pest of brassicas. Economically important hosts are cabbage, cauliflower, Chinese cabbage, broccoli, kohlrabi, radish and mustard. Wild plants like thyme, steaved tree *(Crataeva religiosa)*, an ornamental crop *(Clerodendron fragranspeniflorum)* and spider flower

Catepillars of the cabbage moth feeding on cabbage

(Cleome gynandra) are found to harbour this pest. Cabbage moth has also been recorded feeding on cotton and pigeon pea.

3.6.14.3. The damage caused

Young caterpillars chew off top leaf surfaces. Older caterpillars feed under a web of silk on young leaves, petioles and growing points of the plant, often damaging it entirely by eating most of the soft tissue and leaving only the thicker veins (skeletonisation). In addition to the feeding damage, host plants are often completely soiled with excrement. On cabbage the caterpillars of the cabbage moth skeletonise the outer leaves and bore into the developing head, filling it with frass and excrements. Damage created in the cupping stage results in either aborted or multiple heads. They cause borehole damage with frass and excrements in the developing head. Even a single mature caterpillar per plant is capable of causing economic loss to cabbage at pre- and post heading stages.

Caterpillars nibble on the growing tip of seedlings/transplants of cauliflower causing ‘blindness’. They also cause skeletonisation of outer leaves after planting and discolouration of curd. Caterpillars damage pods and eat the seeds.

Damage caused by catepillars of the cabbage moth

On mustard, caterpillars cause extensive skeletonisation of leaves and webbing of leaves and inflorescences. They also bore holes into pods, eating the seeds.

On kohlrabi caterpillars cause extensive skeletonisation of leaves.

Affected plant stages

Flowering stage, fruiting stage, seedling stage and vegetative growing stage

Affected plant parts

Fruits/pods, growing points, inflorescence and leaves

Symptoms by affected plant part

Fruits/pods: internal feeding; external feeding.
Growing points: external feeding.
Inflorescence: internal feeding; external feeding; webbing.
Leaves: external feeding; abnormal forms; internal feeding; webbing

3.6.14.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

Monitoring is very important in the first stages of the crop. Monitoring is quick, easy and effective in the initial stages of the crop, which is approximately in the first 70 days from planting (or 40 days from transplant). The cabbage moth *(Crocidolomia)* can be detected by looking for the window-like leaf damage caused by the young caterpillars. Check the crop twice weekly in order to detect the caterpillars before they move towards the growing centre of the plant. After this time, when the cabbage plant is larger and structurally complex, it becomes too difficult to detect the caterpillars and sampling becomes much less effective.

Trap cropping

Trap cropping cabbage with Indian mustard in a planting pattern of 15 rows of cabbage followed by mustard rows has been shown to reduce attack by the looper on cabbage. Plant Indian mustard *(Brassica juncea)* as a trap crop between several rows of common cabbage to attract most cabbage moths and some DBM adults. Mustard attracts almost the entire population of cabbage moths and 80% of diamondback moth (DMG). Intercropping cabbage with tomato, which acts as a repellent, can also reduce attacks on cabbage. The cabbage crop is planted 30 days after tomato. Remove the trap crops when these are heavily infested with the pests or else these pests will transfer to the main crop.

Other important cultural practices include field sanitation, crop rotation and intercropping. Please refer to the section on diamondback moth to find more information on cultural practices that can also be applied for the cabbage moth.

3.6.14.5. Remedies

Bio-pesticides and physical methods

Bt (Bacillus thuringiensis)

Spraying with Bt reduces damage by the cabbage moth. It is very important to spray when caterpillars are small and before they bore into the cabbage heads. Spot spraying (spraying only affected plants) has been considered effective when the percentage of plants infested with these caterpillars is below 15%. If it is higher it becomes more efficient to spray the entire field.

Neem

Neem extracts give good control of the cabbage moth. (Cabi, 2000; Osterman and Dreyer, 1995)

3.6.15. Cabbage webworm

3.6.15.1. Scientific and common names

Hellula undalis
Cabbage centre worm, cabbage borer

3.6.15.2. What it is

The cabbage webworm *(Hellula undalis)* is a pest of brassicas in many parts of the world. In Africa, it occurs in Eastern and Southern African regions.

The eggs are small, oval and slightly flattened on the plant surface. They are creamy white when freshly laid, become pinkish the next day and then turn brownish-red with the dark head of the caterpillar visible at one end just before hatching. The eggs are laid singly, or in groups or chains of 2 or 3 on the surface of leaves or on younger parts of the plant. At temperatures between 25° and 29°C, a single female moth lays as many as 150 eggs, which hatch in 4 to 5 days.

Caterpillars are creamy white with light pinkish brown stripes along the body and have a black head. Mature caterpillars have faint stripes. They measure 15mm when fully grown. Duration of larval development varies between 6 to 18 days, depending on temperature and on the host crops. Thus, on cabbage, larval development is completed in 16 to 19 days, but on cauliflower it may require only 11 to 13 days.

Cabbage webworm moth

The pupae are shiny pale brown with a dark dorsal stripe. Pupation occurs in leaf tissue and in tunnels made by the feeding larvae inside the stem. Adults emerge in 7 to 8 days Adult moths are greyish-brown in colour, small and rather delicate with a wingspan of approximately 1cm. Each front wing has a black spot and zigzagging pale brown lines. The adult moth is capable of flying long distances and occasionally migrates to areas well outside its normal breeding range. Adult lifespan is about 4 to 8 days.

Cabbage webworm on kale

Principal host plants are cabbage, kale and all other brassica crops (cauliflower, kohlrabi, broccoli etc). Cauliflowers appear to be the preferred food plant of the cabbage webworm. It is also found feeding on radish.

3.6.15.3. The damage caused

Symptoms

Young caterpillars mine leaves, bore stems and feed externally on the leaves. They then often penetrate the heart of the plant, destroying the terminal bud and prevent heading. While feeding, they spin a silken tube. Plants wilt and frass is exuded from the affected plant parts.

Affected plant stages

Flowering stage and vegetative growing stage

Affected plant parts

Growing points, inflorescence, leaves, stems and whole plant

Symptoms by affected plant part

Growing points: external feeding
Inflorescence: wilt
Leaves: external feeding; internal feeding; webbing
Stems: internal feeding
Whole plant: dead heart; wilt

Young caterpillars mine the leaves, while older caterpillars feed on the underside of rolled leaves within spun webs. Mature caterpillars (last instars) feed on leaves as well as stems and growing points. They are often hidden behind a web of silk and masses of frass (insect faeces). These are usually the first signs noticed.

Caterpillars feeding on young plants frequently cause the death of plants, especially when the larvae feed on the growing point. In older cabbage plants, new shoots are produced and the attacked plants produce several small heads of little commercial value. Caterpillar feeding after heading may cause head stunting. In addition, insect feeding and the presence of caterpillars and/or their excrement reduce the market value of the produce. On kale, young caterpillars mine in the leaves and older caterpillars bore into the stem of the plants. Frass accumulated at the entrance of the tunnel along the stems is an indication of damage.

Cabbage webworm feeding

3.6.15.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

Regular monitoring of young plants in the nursery and after transplant is important. Inspect crops for the presence of caterpillars and damage symptoms.

Use clean planting materials: transplant only healthy, vigorous insect-free seedlings.

Field sanitation

Uprooting and burning of cabbage and kale stalks and crop rotation are important to reduce field populations.

3.6.15.5. Remedies

Biological pest control

Natural enemies

Natural enemies of the cabbage webworm include parasitic wasps (such as *braconid, ichneumonid and chalcidoid wasps*).

Conservation of these natural enemies is important. Care should be taken when deciding on options to manage this or other cabbage pests. The cabbage webworm frequently occurs in the same areas where aphids and diamondback moths are major pests. This may complicate the control of cabbage webworm, since pesticides used to control aphids and other pests, may kill natural enemies of the cabbage webworm, resulting in outbreaks of this pest.

Bio-pesticides and physical methods

Bt (Bacillus thuringiensis)

Bacillus thuringiensis var. aizawai and Bt var. kurstaki are very effective in controlling infestations of the cabbage webworm. *Bt var. kurstaki* is used at weekly intervals and at a rate of 0.5kg/ha. This type of strategy provides effective control of the cabbage webworm. However, continuous use of Bt can induce the development of resistance.

It is important to start control measures early when caterpillars are still young and have not yet penetrated plant tissue.

Bt is a naturally occurring soil bacterium that causes disease on insect pests. It is accepted as an alternative in organic farming and is considered ideal for pest management because it is host specific and is non-toxic on natural enemies and on humans.

Bt is commercially available in most agricultural suppliers. It is sold in various formulations (spray, dust and granule) and strains *(Bt tenebrionis, Bt kurstaki, Bt israelensis, Bt aizawai, Bt san diego).*

They kill the cabbage webworm and do not harm beneficial insects.

Application: *Bt* insecticides should be applied when the first L1-larvae are appearing. Sprays may need to be applied at intervals of 5 to 7 days when populations are high. Because Bt insecticides are UV-degraded, treat crops in the late afternoon.

Some broad-spectrum insecticide derived from fermentation of the naturally occurring soil bacterium *Saccharpolyspora spinosa*, controls many caterpillars, leafmining flies and thrips. It is useful for the management of caterpillar pests in brassicas, including the diamondback moth, the cabbage looper and the cabbage webworm.

Farmer's experiences – homemade Bio-pesticides

Farmers in some countries produce their own homemade Bio-pesticides by collecting diseased DMG larvae (fat and white or yellowish or with fluffy mould on them), crushing them and mixing them with water in a blender. Large tissue clumps are filtered out and the liquid is sprayed onto the crop (Dobson *et al.*, 2002).This preparation is equally effective against the webworm.

Neem

Botanicals, especially neem-based insecticides give good control of the cabbage webworm. Weekly applications of neem products afforded good control in Togo (Ostermann and Dreyer, 1995). It is important to start control measures early when caterpillars are still young and before they have penetrated plant tissue.

3.6.16. Cutworms

3.6.16.1. Scientific and common names

Agrotis spp. (Agrotis segetum and A. ipsilon)

3.6.16.2. What it is

Cutworms *(Agrotis spp.)* occur in Africa from the Cape to the Mediterranean Coast. *Agrotis ipsilon* is one of the most widely distributed species of the cutworm complex. It is generally considered to be distributed worldwide. Distribution of *Agrotis segetum* is limited by temperature. In Africa this cutworm is absent in the inner Sahel since the climate is too harsh.

The eggs are ribbed, globular and small (about 0.5mm in diameter). When newly laid, they are cream coloured turning reddish-yellow to blackish before hatching. Eggs are laid singly or in small groups on moist soil, on weeds or on the stem and lower leaves of host plants or on low growing vegetation. A single female can lay up to 2000 eggs. Preferred substrates are densely growing plants that are relatively low on the ground and fine-textured plant debris in untilled fields. Damp, low-lying areas within untilled fields are particularly attractive for egg-laying moths. Eggs hatch in 10 to 28 days.

Young caterpillars are pale, yellowish-green with a blackish head. Older caterpillars have a plump body; their colour varies from grey, dark green to brown or black with shiny, greasy-looking skin. Fully-grown caterpillars are 4cm to 5cm long. Newly hatched caterpillars feed on the leaves and later on the stems.

Older caterpillars feed at the base of plants or on roots or stems underground. They are nocturnal and hide in the soil or under stones and plant debris during the day. At night they move up to the soil surface to feed. Caterpillars construct burrows or tunnels in the soil about 2.5cm to 5cm deep near the host plant. They pupate in an earthen cell in the soil.

Cutworm

The pupae are about 1.7 to 2.5cm long, smooth and shiny reddish-brown with two dark spines at the tip of the abdomen. They appear almost black in colour just before the moth emerges.

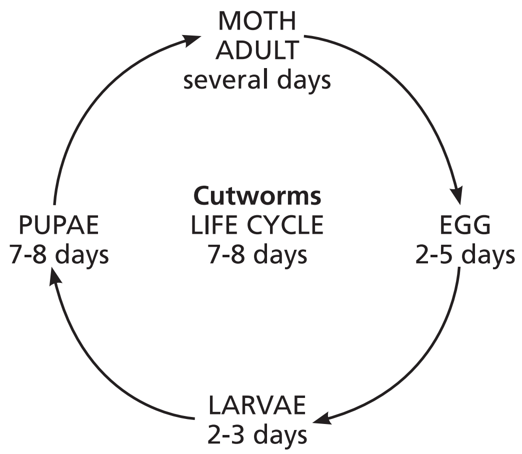
Cutworm pupae

The adult is a medium-sized moth, about 2cm long with a wingspan of 4cm to 4.5cm. The forewings are greyish-brown with black lines or kidney-shaped markings along the side margins. The hind wings are pearly white with dark brownish margins and veins. They are active at night.

Cutworm moth

The life cycle can be completed in 6 weeks under warm conditions.

Cutworms attack cultivated plants belonging to more than 15 families. Common host plants include okra, cabbage, cauliflower, rutabaga, bell pepper, tomato, potato, maize and cotton.



Agrotis ipsilon cutworm lifecycle

3.6.16.3. The damage caused

Symptoms

External feeding on leaves by young caterpillars results in the presence of very tiny round ‘window panes’. Feeding on leaves, stalks and stems results in falling leaves, small holes in the stems or cut stems respectively. Feeding on tubers and roots, results in a variety of holes ranging from small and superficial to very large deep ones.

Feeding by medium to large caterpillars is easier to recognise because whole leaves may fall off the plant after being cut through at the base of the stalk. Alternatively, small holes may be found on the stems and roots at the soil surface. A further sign of their activity is the presence of leaf pieces partly pulled down into the soil.

Agrotis ipsilon damage

The activity of the fully-grown caterpillars is very obvious. Whole plants fall over and on root crops, deep holes become visible at and above the soil surface. Damage to underground tubers (e.g. potatoes) may be difficult to recognise before harvest.

Damage is far more severe under very dry conditions and occurs deeper below the surface (Thygesen, 1971; Esbjerg, 1990).

Cutworm and damage

Affected Plant Stages

Seedling stage and vegetative growing stage

Affected Plant Parts

Leaves, roots and stems

Symptoms by affected plant part

Leaves: "windowpane" holes on leaves; abnormal leaf fall
Roots: Holes ranging from small and superficial to very large deep ones

Young caterpillars feed on leaves and later on stems. Mature caterpillars cause the most damage. They are capable of eating or destroying the entire plant. They girdle and cut-off young seedlings at ground level during the night, dragging them into the tunnel in the soil to feed on them during the day.

- In beans, caterpillars feed on leaves, buds, flowers and pods. Larger caterpillars tunnel into and destroy the bean pod and seeds
- In maize, caterpillars will feed on leaves, silk and ears
- On tubers and root crops, cutworms feed on tubers and roots, boring a wide shallow hole
- Thick-stemmed vegetables such as lettuce and brassicas may have the stem below the ground completely hollowed out. Attacked plants wilt and die

The nature of the soil has a large influence on the rate of infestation. Cutworms tend to be more frequent in soil with plenty of decaying organic material or where organic manure has been applied. Damage is worse where cutworms are present in large numbers before planting. Cutworms often reoccur in the same field, coming with crop residues and dense stands of weeds.

3.6.16.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring and decision making

- Early detection helps to prevent serious damage. Check fields for cutworm before sowing or transplanting
- Monitor damage by counting damaged and freshly cut leaves, freshly cut young plants and holes in leaves and in stems
- Monitoring of cutworm caterpillars should be done at dawn
- Monitoring of cutworm moths can be done by pheromone traps (not available locally)
- Control before thinning is advisable where high numbers of cutworms are present. Control is normally not needed when plants are about 25 to 30cm tall, but heavy attacks can kill even taller plants. Bigger seedlings are more tolerant to damage

Control options

- Ploughing exposes caterpillars to predators and to desiccation by the sun
- Fields should be prepared and vegetation and weeds destroyed 10 to 14 days before planting the crop in the field. If the field is planted soon after land preparation, some cutworms that may still be alive will attack the new crop
- Delaying transplanting slightly until the stems are too wide for the cutworm to encircle and/or too hard for it to cut through may reduce cutworm damage
- Hand picking of caterpillars at night by torch or very early morning before they return to the soil is useful at the beginning of the infestation
- Flooding of the field for a few days before sowing or transplanting can help kill cutworm caterpillars in the soil

3.6.16.5. Remedies

Biological pest control

Natural enemies

Cutworms are attacked by a large range of natural enemies. The most important are parasitic wasps and flies and some predators. The parasitic wasp *Cotesia (Apanteles) ruficrus* has been used in biological control programmes. The most common predators include ground beetles, lacewings, praying mantis, ants and birds. Hens are useful because they dig out and eat cutworms present near the soil surface. They are very effective when confined to garden beds prior to planting.

Parasitoids:

1. Braconid: *Snellenius manilae* is a small Braconid wasp species. It looks like Cotesia except that it has a triangular closed cell on its front wing and has hairy eyes. This parasitoid wasp is host specific. It only parasitises cutworm larvae. A female wasp lays 3 to 5 eggs

in a cutworm larva. The parasite feeds off the body fluids and the larva for its development. Cocoons are formed next to the host's body. Lifecycle takes about 4 to 8 days. A wasp lives for about 1 week
2. *Cotesia spp*
3. Tachinid fly

Bio-pesticides and physical methods

Neem (Azadirachta indica)

Experiments in Sudan show that spraying aqueous neem seed and neem leaf extracts 3 times at weekly intervals, starting directly after tuberisation reduced early infestation by cutworms on potato leaves. To prepare the extracts, leaf and seed powder were soaked in water at a rate of 1kg per 40l of water, stirred thoroughly, left overnight and passed through a sieve before spraying (Siddig,1987).

Bait traps

Baits consisting of flour and water and containing Bt, or other insecticides *(e.g. pyrethrum)* are recommended. Baits are more effective when other food is limited.

How to make bait:

1. Mix 100g bran or maize flour, 10g sugar (1 small tablespoon) and 5g of pyrethrum powder with 200ml water thoroughly
2. Sprinkle the mixture closely around the plants in the affected areas

The cutworms will eat the bait and die.

or

1. Mix equal quantities of hardwood sawdust, bran and molasses with enough water to make the mixture sticky
2. Spread around the plants in the evenings

The bait attracts the cutworms and as they try to pass through it, they get stuck and die.

Protective collars

Protective collars can be made from plastic or paper cups, cardboard tubes from paper towels or toilet paper, plastic drink bottles with ripped-out bottoms, sturdy cardboard and milk cartons. Place the collar around the young plant just after planting and push into the soil to prevent the cutworm from attacking the stem.

Sticky substances

Sticky substances such as molasses, diatomaceous earth, saw dust, or crushed eggshells placed around the base of each plant. When cutworms emerge to feed, it will come in contact with the trap, get stuck, harden and die.

Ashes

Ashes are reported to deter cutworms when spread on seedbeds, around plants, or mixed with the soil in the planting holes. The ash layer must be renewed regularly.

Wooden stick

A thick dry stick inserted on the side of the seedlings can act as a mechanical barrier, reducing loss of plants by cutworms.

3.6.17. Cowpea seed beetle

3.6.17.1. Scientific and common names

Callosobruchus spp. (Callosobruchus maculatus, Callosobruchus chinensis)
Cowpea weevil, cowpea seed weevil, spotted cowpea bruchid/chinese bruchid, Adzuki bean beetle

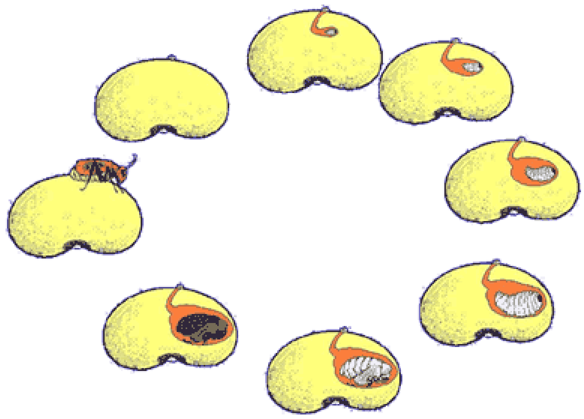
3.6.17.2. What it is

Callosobruchus beetles are important pests of pulses.

Eggs are small (0.75mm long), clear, shiny and smooth and oval or spindle shaped. They are firmly glued to the surface of pods and pulses. If the pods have opened, eggs are laid directly onto the seeds. Eggs are small, smooth and have domed structures with oval, flat bases. When newly laid, they are translucent grey and inconspicuous. Upon hatching, the empty egg shells are white and clearly visible to the naked eye. Eggs hatch within 5 to 6 days of oviposition.

The larvae are whitish and somewhat C-shaped with small heads. Upon hatching, they bite through the base of the eggs and bore into the seeds where they spend the whole lifecycle feeding on the seed. The larvae pupate inside the seed.

Pupation takes place in a chamber just under the testa of the seed. Pupation takes about 7 days to complete.



Cowpea seed beetle life cycle - bmdtran.net

Adult beetles are small, about 2 to 3mm long, somewhat teardrop shaped and slightly elongated. They are pale to reddish brown with black and grey patches and two black spots near the middle on the wing cases. The posterior part of the abdomen is not covered by the wing cases. They do not feed on stored produce. They have a short lifespan, and do not usually live longer than 12 days. During this time the females lay up to 115 eggs. The optimum temperature for egg-laying is about 30° to 35°C.

The whole lifecycle takes about 4 to 5 weeks. Cowpea bruchids are major pest of cowpeas, pigeon peas, soybean, green gram and lentils.

Cowpea seed beetle - Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org/

Cowpea seed beetle

3.6.17.3. The damage caused

Symptoms

In the early stages of attack the only symptoms are the presence of eggs glued to the surface of the pulses. As development occurs entirely within the seed, the immature stages can normally not be seen. However, they can be detected after pupation takes place; although the seed coat of the bean is still intact, a round 1mm to 2mm window is apparent at the location where the beetle is pupating. The adults emerge through these windows leaving round holes in the grain that are the main evidence of damage.

Affected plant stages

Fruiting stage and post-harvest

Affected plant parts

Seeds

Infestation commonly begins in the field, where eggs are laid on maturing pods. As the pods dry, the pest's ability to infest them decreases. Thus, dry seeds stored in their pods are quite resistant to attack, whereas the threshed seeds are susceptible to attack throughout storage. Infestation may start in the pods before harvest and carry over into storage where substantial losses may occur.

Levels of infestation in storage are strongly influenced by the type of storage structure employed and the variety of seed. Storage structures that maintain high levels of moisture in seeds are more prone to high levels of infestation. The value of dried pulses is strongly affected by levels of bruchid attack.

3.6.17.4. Cultural practices to prevent its occurrence

Cultural practices

Intercropping

Intercropping maize with cowpeas and not harvesting crops late, significantly reduced infestation by several species of cowpea seed beetles (*C. maculatus, C. rhodesianus, C. chinensis* and the bean bruchid *Acanthoscelides obtectus*) in Kenya (Olubayo and Port, 1997).

Sanitation

- Good store hygiene plays an important role in limiting infestation by cowpea seed beetles
- Remove infested residues from the previous season's harvest
- General hygiene is also very important

Solarisation

Solarisation (sun drying and heating) can be used to control infestations without affecting seed germination. When small lots are stored, sun-drying the beans can give substantial protection. Sun-dry beans periodically in a thin layer for periods of up to 4 hours. Solar heaters or transparent bags of seeds left in the sun can provide excellent control of infestations (Ntoukam et al., 1997; Ghaffar and Chauhan, 1999).

Resistant varieties

During the last few decades, researchers in Africa have been looking for pest resistance in cowpeas. The varieties 'Mouride' and 'CRSP Niebe' are reported to be resistant to cowpea seed beetle (IITA, CRSP).

Ashes

Farmers often mix cowpea grains with ash to control the cowpea seed beetle. To be efficient, it should be at least 5% of ash (Gómez, C).

3.6.17.5. Remedies

There are no known remedies.

3.6.18. Larger grain borer (LGB)

3.6.18.1. Scientific and common names

Prostephanus truncatus

3.6.18.2. What it is

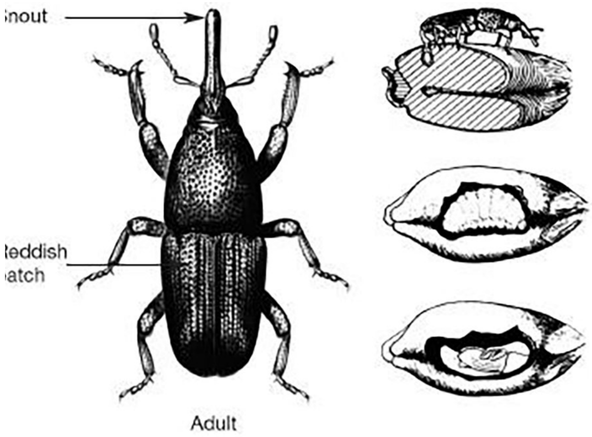
The larger grain borer was accidentally introduced from Central America into Tanzania in the late 1970s and spread to other countries in the region. In West Africa it was first found in Togo in the early 1980s. It has now spread to many African countries, becoming the most destructive pest of stored maize in both West and East Africa. To date, it has been reported in Benin, Burkina Faso, Burundi, Ghana, Guinea Conakry, Kenya, Malawi, Mozambique, Namibia, Niger, Nigeria, Rwanda, South Africa, Tanzania, Togo, Uganda and Zambia. In some of these countries it has become a serious pest of stored maize and dried cassava.

Eggs are laid in tunnels and chambers bored by the females in the food source. Larvae hatch from the eggs after 3 to 7 days. The larvae are white, fleshy and sparsely covered with hairs and have three pairs of legs. They develop within the grain or in the flour that accumulates by the feeding action of the adults. They pupate inside the food source. The adult beetle is 3mm to 4.5mm long and dark brown in colour. It has a cylindrical body shape, when viewed from above and the rear of the insect is square shaped. The thorax bears rows of teeth on its upper front edge and the head is turned down underneath the thorax so that it cannot be seen from above. The female lays 30 to 50 eggs into the produce (maize, cassava, etc).

LGB adult

The lifecycle can be completed within 25 to 26 days in optimum conditions - this is at high temperature (about 30°C) and relatively high humidity (about 70% RH, + 13% grain moisture content). Development takes longer under cooler or drier conditions.

The larger grain borer develops more rapidly on maize grain than on cassava.



LGB life stages

3.6.18.3. The damage caused

Symptoms

Adults tunnel through stored maize grain or other starchy products, such as dried cassava chips, creating large quantities of dust.

The larger grain borer is reported to breed only in maize and cassava. The adults can, however, live in and damage many stored products such as bulrush millet sorghum, yam and wheat, as well as structural wood and wooden utensils.

LGB on maize

Adults also bore into a wide range of foodstuffs and other materials such as bamboo, gourds, plastic and soap. In heavy infestations, wooden storage structures may become damaged and act as reservoirs of infestation from which the new harvest may be attacked. The larger grain borer also occurs in the natural environment. It is able to breed on dead, dry wood of a range of trees, as well as dried stems of cassava and maize plants. Studies of this pest using pheromone traps showed that it was widespread in the natural vegetation in the Tsavo National Park, Kenya (Nang'ayo *et al*., 1993, 2002; Nansen *et al*., 2004).

Symptoms by affected plant part

Seeds: holes, large quantities of dust

Affected plant stages

Post-harvest

Affected plant parts

Seeds

The larger grain borer is a serious pest of stored maize and dried cassava roots and will attack maize on the cob, both before and after harvest. Adults bore into the cassava or maize husks, cobs or grain, making neat round holes and tunneling extensively producing large quantities of grain dust as they tunnel. The adults prefer grain on cobs to shelled grain, thus damage on unshelled maize is greater than on loose, shelled maize.

When infesting stored maize cobs with husks intact, the adults frequently begin their attack by boring into the maize cob cores and eventually gain access to the grain at the apex of the cob by crawling between the cob and husk. They may also bore directly through the husk. They cause considerable losses in stored maize; weight losses as high as 35% have been observed after only 3 to 6 months storage in East Africa. Losses in dry cassava can be very high too; the dried roots may be readily reduced to dust by boring adults. Average losses of 19% have been recorded after 6 months storage and as much as 30% in some cases.

The larger grain borer is spread over longer distances almost entirely through the import and export of infested grain. Local dispersal is through the local movement of infested maize and dried cassava and by flight activity of the adult beetles.

Although the larger grain borer develops best at high temperature and relatively high humidity, it tolerates dry conditions and may develop in grain at low moisture in contrast to many other storage pests, which are unable to increase in number under low moisture conditions. For this reason, infestations of the larger grain borer, usually found together with other storage pests, is predominant under dry conditions.

Attack by the larger grain borer is sporadic. Pest incidence may be low for several years and then suddenly increase in a "bad" year.

3.6.18.4. Cultural practices to prevent its occurrence

Cultural practices

Detection and inspection methods

Except when populations are very high, it is not possible to detect the pest by visual inspection. The immature stages develop within the food source and therefore they are not normally seen. Traps baited with the chemical attractant (pheromone) produced by the male beetle are useful to detect and monitor adult beetles. This pheromone is synthesised in the laboratory and loaded into plastic capsules, which then release the pheromone slowly through their walls. A pheromone capsule is then placed in a suitable trap.

Flight traps, such as funnel, delta or wing traps baited with the pheromone are considered the best for monitoring the larger grain borer. These traps are suspended about 1m to 2m from the ground outside the store or the standing maize crop. They should be placed at least 100m from stores or from the field to avoid attracting the beetles to these food sources. The traps are useful for researchers and for plant protection authorities. Traps are an important tool for phytosanitary purposes and for warning farmers about impeding attack by the larger grain borer.

However, small populations already feeding on maize or cassava in a store cannot be detected by pheromone traps because the pest does not react to the pheromone until dispersing from its food source. Only when the population has increased to an extent whereby the infestation is obvious and the beetles are starting to disperse, will the traps catch beetles. Presently, the only means of assessing infestations in store is by manual sampling of the produce.

Although the traps and pheromones are available commercially, they are expensive and not easily available.

Store hygiene

Good store hygiene is very important in limiting infestation.

- Clean stores thoroughly between harvests
- Remove and burn infested residues before the new stock is stored
- Immerse used sacks in boiling water to eliminate residual infestations
- Eliminate residual infestation in the wooden structure of the store by removing timber or by fumigating the whole store under a gas-tight sheet

Harvest timely

When maize is ready for harvest, do not leave it for too long in the field; the larger grain borer or other storage pests could attack it. Studies in Benin have shown that maize harvested 3 weeks after physiological maturity gave better economic returns when stored for 8 months than maize harvested 1 or 7 weeks after physiological maturity.

Leaving maize in the field for extended periods after physiological maturity resulted in severe grain losses after 8 months of storage, mainly due to damage by the larger grain borer. However, early harvested maize had a higher proportion of mouldy grain (Borgemeister et al., 1998).

Post harvest

In locations where the larger grain borer is a problem, shell infested cobs as soon as possible before storing and dry completely to below 12% moisture (safe for bagging); when the kernels are too hard to bite through, they are usually dry enough for bagging. Treat the grain with a botanical pesticide. Traditional varieties with good husk cover are much less likely to be attacked, thus when storing these varieties on the cob, reject any cobs with damaged or open sheathing leaves. (Meikle et al, 2002; Borgemeister, et al, 2003).

In the case of cassava, leave roots in the ground for as long as possible to reduce the storage period in order to minimise losses. After harvest, sun-dry the cassava and immediately transfer it to sealed containers.

Storage

- Store only clean produce. Carefully inspect the store before the newly harvested maize or cassava is placed inside and sort out infested cobs or roots for immediate use
- Store the grain in a suitable container. The larger grain borer easily attacks grains stored in hessian bags or guards. Moreover, this pest also damages guards. The most suitable containers are those that can be sealed such as metallic containers, old oil drums or mudded cribs or baskets. They provided a very effective barrier to pest attack and can be used, provided the stock is sufficiently dried so that ventilation is not required

- Use brick or stones to construct the granaries; wood and grass would encourage breeding and multiplication of the larger grain borer
- Give preference to a corrugated iron sheet roof for the stores to avoid harbouring the pest. If using thatch grass, it should be a thick layer and cone shaped; the roofing should be replaced after a certain period to minimise leaking

Sell the maize stock within 3 months

Sell the maize within 3 months since the extent of larger grain borer infestation during the first 3 months of storage is generally low. Alternatively, split the maize harvest into two portions. One portion is destined for consumption, since the extent of large grain borer infestation during the first 3 months of storage is generally low. The other portion can be kept longer in the store and should be treated if larger grain borer was observed the previous year. If not, the stock should be regularly inspected. If the pest is found subsequently, then grain shelling and treatment either with a botanical or with an inert dust is required.

3.6.18.5. Remedies

Biological pest control

Natural enemies

The beetle *Teretrius* (formerly *Teretriosoma) nigrescens*, which is a specific predator of the larger grain borer in Central America, has been introduced into Africa. The adult and the immature stages of this predatory beetle feed on eggs and larvae of the larger grain borer.

The predatory beetle has been released in Benin, Ghana, Guinea-Conakry, Kenya, Malawi, Tanzania, Togo and Zambia. It became well established and spread in most countries. However, despite the successful introductions, there are still regular outbreaks of the larger grain borer and farmers still suffer losses. Nevertheless this predator has a role to play in the management of the larger grain borer, as it is able to reduce the density of the pest.

Bio-pesticides and physical methods

Effect of Neem on storage pests

Several plants have been reported to control the larger grain borer. See table below:

Plant	Plant part	Product/concentration	Effect on damage
Castor beans	Seed	10% ethanolic extract	-
Neem	Seed	5-10% slurry	< 10% damage
Neem	Oil	1.5% (vol/vol)	< 16% damage
Pyrethrum	Flower	0.5% powder (w/w)	Highly effective
Velvet leaf	Leaf, root	2.5-10% slurry	< 10% damage

Source: Modified from Stoll, 2003

Using plant material in the form of slurry has given better results than plant powders. The slurry can be prepared by weighing out powder into 150ml containers and adding sufficient water to give a 10% concentration (w/w) and stirring until a smooth paste is obtained. Then, the grain is poured into prepared slurries and stirred with a rod until all grains are coated (Tierto, as cited by GTZ and Stoll, 2003).

Neem shows considerable potential for controlling pests of stored products. Jute sacks are also treated with neem oil or neem extracts to prevent pests – particularly, weevils and flour beetles – from penetrating for several months.

However, neem products are not as effective for protection of maize grain against the larger grain borer as against grain weevils. Pyrethrum is much more effective. Since these two pests are usually found together, a mixture of neem and pyrethrum known as ("Nimpyr") seems as a better option to protect stored maize. Trials in Tanzania showed much lower grain damage in maize treated with "Nimpyr" (0.5 to 6% kernel infested) compared with untreated maize (17% to over 90%) 6 months after treatment.

But there are some shortcomings to the use of this mixture, namely:

- A relatively large amount of the mixture is needed to protect grain (2 to 3kg per 100kg grain)
- The labour input needed to manufacture "Nimpyr" is considerable
- The active ingredients of pyrethrum deteriorate relatively rapidly when exposured to heat and/or light
- Pyrethrum has an unpleasant odour, whilst neem has a bitter taste (although this can be eliminated by soaking and washing the grains in water for a sufficient period)
- The mixture is unlikely to give protection in maize stored on cobs, since the pests are protected under the husks

How to prepare and use "Nimpyr"

- Collect or purchase ripe neem fruits; tease out the seed kernel, wash and dry in the shade for 3 to 5 days. Then pound the kernels into a fine pulp, dry for a further 1 to 2 days, crush with the fingers and sieve. Pound and sieve again until a fine powder is obtained. Do not use the same mortar for food processing because the bitter taste of the neem seeds will remain
- Pluck the dry florets of pyrethrum, pound in a mortar and sieve. Florets and powder quickly lose their effect in the sunlight. Therefore, store florets away from the light if they cannot be processed immediately. Use powder straight away
- To treat 100kg of grain, mix 1.5kg to 2kg of neem seed powder with 0.5 to 1kg of pyrethrum floret powder. When the grain is dried properly, distribute this preparation over it and mix in carefully. Store without delay
- Grain intended for consumption must be soaked and washed in a lot of water before use to eliminate any unpleasant odour or taste

(*Source:* GTZ- Plant derived products as protectants against the larger grain borer and other stored-food pests).

Neem oil is an extremely effective and cheap protection for stored beans, cowpeas and other legumes. It keeps them free of bruchid beetle infestations for at least 6 months, regardless of whether or not the beans were infested before treatment. This process may not be suited to use in large-scale food stores, but it is potentially valuable for household use and for protecting seeds being held for planting. The treatment in no way inhibits the capacity of the seeds to germinate.

Neem has also been used in India to protect stored roots as well as tubers against the potato moth. Small amounts of neem powder are said to extend the storage life of potatoes for three months. (OIA, 1992).

Ash/Chilli mixture

Ash/chilli mixture and a thick layer of paddy husk ash covering the stock is reported to be effective in preventing larger grain borer attack.

How to prepare an ash/chilli mixture to protect maize from LGB:

- Dry the chillies and pound them to a fine powder
- Sieve cold wood ash from the fireplace
- Mix 2kg of wood ash with 1 tablespoon of chilli powder. Make sure they are properly mixed
- Mix 1 part ash/pepper mixture with 4 parts of dried maize grain
- Store

(*Source:* D. Wanjama, KIOF; Borgemeister *et al.*, 2003)

Diatomite

The use of diatomaceous earth for control of grain boring insects during storage has in many cases been successful. Mix diatomite powder with grain before storing in bags or dust newly harvested dry cobs before storing them with diatomite. Use 1kg diatomite per bag of maize or grain.

Some confusion exists on the use of diatomaceous earth, as finer ground diatomite products commonly used for sifting beverages is not effective as insect control. However unprocessed products work on the same principles as laterite mentioned below, by dehydrating the insects and by destroying the insects' articulations.

Laterite

The common red soil of the arid tropics, when finely crushed protects stored grains and beans. In family grain stores or in sealed clay pots, the dust deters insects from boring into or laying their eggs on the dusted grains. Laterite rubs off the waterproof waxy coating on the insect bodies and they dehydrate and die.

In sealed storage pots insects suffocate because enough dust is poured in with grain to exclude air and trapped insects dehydrate and die as their outer coating is damaged by abrasion.

3.6.19. Leafmining flies (leafminers)

3.6.19.1. Scientific and common names

Liriomyza spp

3.6.19.2. What it is

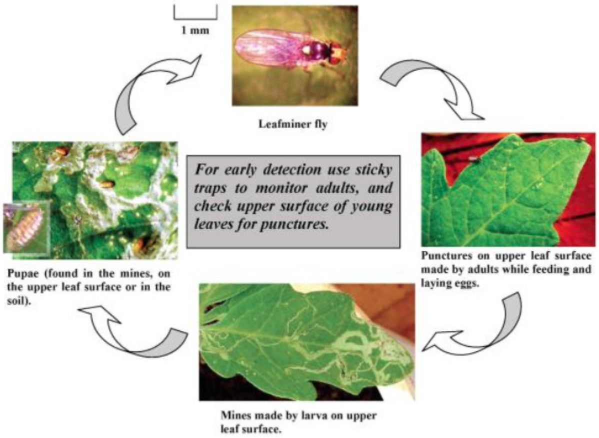
Leafmining flies are serious pests of vegetables and ornamental plants worldwide. They are occasional pests of brassicas. *Liriomyza brassicae* is cosmopolitan. In Africa it is active in Egypt, Ethiopia, Kenya, Mozambique, Zimbabwe, Cape Verde and Senegal. Host plants are primarily crucifers.

Two species of serpentine leafmining fly, *L. trifolii* and *L. sativae*, are considered serious pests of tomatoes. Both species are cosmopolitan.

In Africa, *L. trifolii* has been reported in several countries, including Kenya, Mauritius, Reunion, Senegal, South Africa and Tanzania.

L. brassicae has also been reported for many years as a pest on brassicas and legumes, but in general, the damage done to mature crops is largely superficial.

Eggs are very tiny (about 1.0mm long and 0.2mm wide), greyish or yellowish-white and slightly translucent. They are laid inside the leaf tissue, just below the leaf surface. In some instances eggs are laid below the epidermis of fruits/pods (e.g. peas). Eggs hatch in about three days.



Leafminer life cycle

Leafminer larvae

Larvae are small yellow maggots (about 2 to 3mm long when fully-grown). They are found feeding inside the leaf tissue, leaving long, slender, winding, white tunnels (mines) through the leaf. They pass through 3 larval stages. After 5 to 7 days the maggots leave the mines and pupate either on the leaf surface or - more commonly - in the soil. In some cases, maggots pupate within the mines.

Leafminer damage on tomato leaf

The pupae are very small, (about 2mm long and 0.5mm wide) oval, slightly flattened ventrally with variable colour varying from pale yellow-orange to golden-brown. They have a pair of cone-like appendages at the posterior end of the body. Adults emerge 4 to 5 days after pupation.

Leafminer fly - Central Science Laboratory, Harpenden Archive, British Crown, Bugwood.org

Leafmining adult flies are small, about 2mm long. They are greyish to black with yellow markings. Female flies are slightly larger than males.

Major species of leafmining flies in Africa are:

- The serpentine leafminer *(Liriomyza trifolii)*
- The vegetable leafminer *(L. sativae)*
- The cabbage leafminer *(L. brassicae)*
- The pea leafminer *(L. huidobrensis)*

Leafminers are able to colonise a wide range of plants (primarily although not exclusively *Solanaceae, Leguminosae* and *Asteraceae*). *Liriomyza* flies are pests to horticultural crops and potatoes in the tropics and subtropics. The most common species, *L. sativae, L. trifolii and L. huidobrensis*, feed on a wide range of plants. Main host plants include cabbage and other brassicas (cruciferous crops), okra, onion, pigeon pea, bell pepper, cucumber, pumpkin, cowpea, potato, passion fruit, tomato and common bean.

3.6.19.3. The damage caused

Symptoms

Female flies puncture leaves and in some instances also fruits/pods (e.g. peas) with their ovipositor to feed and to lay eggs. These punctures can serve as an entry point for disease-causing bacteria and fungi, but in most cases they are not of economic importance. However, they can be a problem for export products. Eggs are laid inside the plant tissue and they cannot be removed through washing; this may lead to rejection of the produce when their presence is detected during import inspection.

Damage by maggots feeding in the plant tissue is economically more important than the feeding punctures of adult flies. Maggots feed between the upper and lower surface of the leaf making tunnels or mines as they move along. Although individual mines on leaves do not produce much damage, heavy attacks, especially on seedlings, may result in dying off of young plants. Heavy attack leads to large-scale necrosis of leaf tissue, eventual shrivelling of the whole leaf and may result in complete defoliation of crops. Defoliation of tomato plants may also expose fruits to sunburn and thus affect their market value.

Heavy infestation reduces the photosynthetic capacity of the plant and affects the development of flowers and fruits. However, mature plants of most crops such as tomato and cabbage can withstand considerable leafmining, especially on the lower or outer leaves. In other crops, where feeding occurs on the marketable part of the crop, even slight damage may lead to rejection of the crop. This is particularly important for export crops, as most Liriomyza species are considered quarantine pests in the EU and there have been rejections of produce exported to Europe.

Affected plant stages

Seedling and vegetative growing, flowering and fruiting stages

Affected plant parts

Leaves and pods

Symptoms by affected plant part

Feeding and females laying their eggs- result in white puncture marks on leaves. These punctures are easily seen and are the first signs of attack
Feeding by maggots leaves irregular mines on the leaves, with occasional thread-like black frass inside the mine. Severely mined leaves may turn yellow, disfigure and drop

Leafminer damage

Leafminer damage on onion

3.6.19.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring and inspection methods

Small black and yellow flies may be detected flying closely around the crop or on the leaves. Inspection of the leaf surface will reveal punctures of the epidermis and the greenish-white mines in the leaves. Feeding maggots will be found at the end of the mine. When the maggots have already left the mine to pupate, the mine will end with a small convex slit in the epidermis. Occasionally the pupae may be found on the leaf surface, although in most cases they pupate in the soil.

One monitoring technique for leafminers used in fresh market tomatoes in the USA is to place plastic trays beneath plants at several randomly chosen places in the field. Mature larvae that drop from foliage accumulate on the trays and pupate there, providing a measure of leafminer activity. Visual rating systems to assess the total number of leafminers on tomatoes have also been developed. The flies can also be monitored by using yellow sticky traps.

It is also important to monitor the presence and activity of natural enemies. Absence of pupae on leaves or in trays placed beneath plants, even if new mines are present, is an indication that natural enemies are keeping leafminers controlled.

The economic importance of damage by *Liriomyza* leafminers depends on the plant stage and on the crop. These factors must be considered when determining whether to implement control. Young plants can withstand less damage than older ones. On leafy crops such as spinach, lettuce and chard, a 5% threshold level is often used. Much more damage can be tolerated in crops where the leafminers affect the leafy, non-marketable parts of the plant than in crops where the marketable part is attacked, particularly in high value crops.

Leafminers can also be monitored by foliage examination for the presence of mines and larvae and by trapping adult flies with yellow sticky traps. Yellow sticky traps used for mass trapping can effectively control the pest at low densities. Visual rating systems to assess the total number of leafminers on tomato have been developed in the USA.

Cultural control
Normal agricultural hygiene can play an important part in controlling leaf miner damage:

- Hand-picking and destroying of mined leaves
- Destroying all infested leaves and other plant material after harvest
- Destroying pupae before planting a new crop: ploughing and hoeing can help reduce leafmining flies but exposing pupae, which then would be killed by predators or by desiccation. Flooding the soil followed by hoeing could kill or release much of the buried pupae
- Where new stock is obtained as seedlings rather than seed, check carefully and destroy infested plants before planting to prevent introduction of pests including leafminers
- Solarisation can kill pupa in the soil

3.6.19.5. Remedies
Biological pest control
Natural enemies
Leafmining flies have a wide range of natural enemies, mainly parasitic wasps, which normally keep them under control. However, the indiscriminate use of broad-spectrum pesticides disrupts the natural control resulting in major leafminer outbreaks.

The three major species present *(L. sativae, L. trifolii and L. huidobrensis)* have been accidentally introduced. Local parasitic wasps now attack these leafmining flies, but they only afford satisfactory control when they are present early in the crop cycle.

One of the most efficient parasitic wasps for control of leafmining flies, *Diglyphus isaea*, is present in many African countries and is giving satisfactory control on some crops. However, this parasitic wasp often comes too late to prevent early damage and farmers resort to pesticides too early, thus preventing population build-up of this natural enemy affecting its efficiency. It is important to conserve this and other naturally occurring natural enemies.

Bio-pesticides and physical methods
Neem
Neem-based pesticides are used for control of leafmining flies. Neem products reduce fecundity and longevity of flies and disrupt the development of the maggots. They can be applied as drench or as foliar sprays.

Weekly applications of aqueous neem seed extracts (ANSE) at 60g/l and neem oil (2.5% to 3%) reduced leafminer damage on tomato (Ostermann and Dreyer, 1995).

Weekly foliar sprays with a commercial neem product at rates of 25g and 50g/l water and a spray volume of about 900l/ha controlled leafmining flies on experimental tomato fields in Kenya. Five applications were done starting 20 days after transplanting. Emergence of leafmining flies decreased with increased dosage (ICIPE).

In Kenya, the integration of neem products into the management of leafmining flies in high value crops (e.g. snow peas, French beans and cut flowers) resulted in the increase of the beneficial wasp *Diglyphus isaea*, a considerable reduction of pesticide use and of reduced rejection of the produce due to leafminer damage (ICIPE).

Traps
Yellow sticky traps used for mass trapping and monitoring can effectively control the pest at low densities.

3.6.20. Mango seed weevil

3.6.20.1. Scientific and common names

Sternochetus mangiferae
Mango nut weevil, mango stone weevil

3.6.20.2. What it is

The mango seed weevil is one of major pests of mangoes in East Africa.

Mango seed weevils

Eggs are elliptical, about 0.8mm long and 0.3mm wide and are creamy-white in colour when freshly laid. They are laid singly in small cavities made by the female in the skin of young fruits. There are reports that eggs may also be laid into inflorescences. The female then covers each egg with a brown exudate and cuts a very small crescent-shaped area (0.3mm) in the fruit, near the back end of the egg. The wound creates a sap flow, which hardens and covers the egg with a protective coating. Several eggs may be laid in each fruit. Incubation requires 5 to 7 days.

Larvae are white grubs with a curved body, brown heads and are legless. Newly hatched larvae are extremely slender and elongated and about 1mm long. Mature larvae are about 17mm long. After hatching, the larva burrows through the flesh of the fruit and

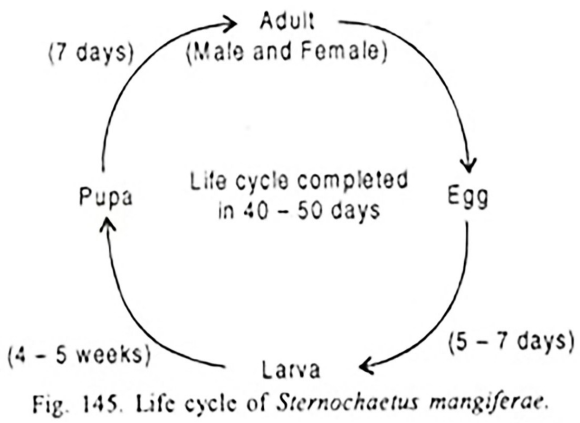
Rhozoctonia on seedlings

into the seed where they feed until pupation. The development of the larva is usually completed within the maturing seed, but also very occasionally within the flesh.

Pupae are whitish when newly formed, but change to a very pale red colour just before the adult emerges. They are about 8mm long and 7mm wide. Pupation takes place in the seed within the stone of the fruit.

Adults are weevils with a compact body, about 8mm long. They are dark greyish-brown with paler patches. They are usually active at dusk. Adults can fly, but they are not known to be strong fliers. However, there are reports that they are able to fly longer distances than previously thought. They pretend to be dead when touched or disturbed.

Adults are well camouflaged on the bark of mango tree trunks, in branch terminals, or in crevices near mango trees during non-fruiting periods. They may also live in leaf litter around the tree. During flowering, the adults leave their sheltered areas and move into the canopy of the tree to feed on new growth and to mate. Females start laying eggs 3 to 4 days after mating, when the fruit is about marble-size. Adult weevils feed on mango leaves, tender shoots or flower buds. They can live for two years.



Rhozoctonia on seedlings

The total life cycle takes 40 to 50 days.

Complete development of the mango seed weevil is only possible in mangoes.

3.6.20.3. The damage caused

The larva, which is the damaging stage of the pest, enters the fruit burrowing through the flesh into the seeds, where they feed until pupation, destroying the seed. Early attack (when the fruits are forming) leads to premature fruit fall. If the attacks occur at a later stage, fruit infestation is very difficult to detect, since there are no external signs of infestation, except for an inconspicuous egg-laying scar and consequent feeding activity in the seed remains undetected.

Weevils leave the fruit after it has fallen and decayed or when the fruit is ripe. Thus, yield is usually not significantly affected. When the adult emerges, it tunnels through the flesh into the open, leaving a hole in the fruit skin. In late-maturing varieties, it causes post-harvest damage to the pulp as the tunnel turns hard, making the fruit unmarketable. This hole also serves as an entry point for secondary fungal infection.

Mango seed weevil is a quarantine pest. Probably its greatest significance as a pest is to interfere with the export of fruit because of quarantine restrictions imposed by importing countries and the market requirement for blemish-free fruit. This is particularly troublesome in the case of the mango seed weevil because, in many instances, weevil attack remains undetected in the field and is first noticed in storage or in transit.

Weevil feeding reduces the germination capacity of seeds. All the evidence suggests that weevils spread into clean areas through the movement of infested fruit for propagation and consumption. In Australia, young orchards planted from weevil-free-nursery stock have been shown to be free of seed weevil infestation for a number of years after establishment, even in areas known to have seed weevil (Pinese and Holmes, 2005).

Symptoms

Infested fruits are difficult to detect to the untrained eye. The cuts made by egg-laying females are small and generally soon heal, leaving very small, dark, crescent-shaped marks on the fruit skin. Infested fruits present internal rot on the outer surface of the stone. The stones also show holes and the cotyledons turn black and become a rotten mass. When the adult emerges, a hole is visible in the fruit skin, which also serves as an entry point for secondary fungal infection.

Mango seed weevil

Mango seed weevil - Lesley Ingram, Bugwood.org

Affected plant stages

Fruiting stage and post-harvest

Affected plant parts

Fruits and seeds

Symptoms by affected plant part

Fruits: internal feeding
Seeds: internal feeding

3.6.20.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

Weevil attack can be detected by monitoring for egg-laying marks on young fruit. Regular fruit scouting is important to detect adult activity during fruit growth.

Sanitation

Good orchard sanitation is very important. Collect and destroy all scattered stones and fallen fruits. Chop them finely or bury them deeply (about 50cm deep).

Keep tree basins clean, remove fallen fruit, seed and plant debris to prevent hiding of adult weevils.

Orchard quarantine

Avoid movement of fruits from areas known to have mango seed weevils to areas where young orchards, free of seed weevil, have been established.

A strict policy of not bringing mango fruit into the orchard and its surroundings will greatly reduce the chance of infestation.

3.6.20.5. Remedies

Bio-pesticides and physical methods

Sticky bands

In areas with a history of high infestation, applying sticky bands at the upper end of tree trunks when the trees start flowering helps reducing migration of weevils to branches for egg laying.

3.6.21. Mealybugs

3.6.21.1. Scientific and common names

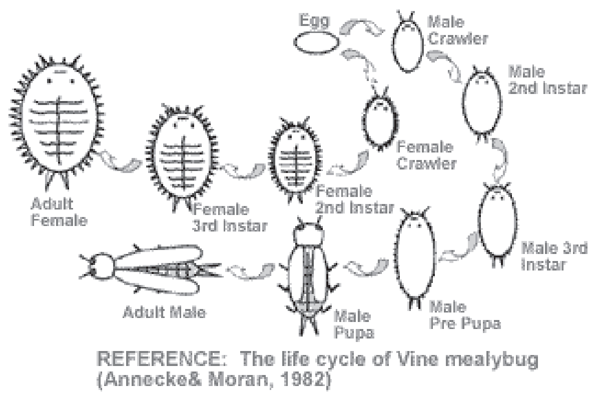
Phenacoccus ssp., Planococcus spp., Pseudococcus spp., Rastrococcus spp., Ferrisia virgata, Dysmicoccus brevipes, Saccharicoccus sacchari

3.6.21.2. What it is

Mealybug eggs are very small and are laid under a white, loose woolly wax, which remains attached to the abdomen of the females. A female may lay between 50 to 600 eggs.

Very small nymphs are flat, oval and yellow. Older nymphs of some species are covered with fluffy, white wax. Older female nymphs resemble the adults, but older male nymphs secrete a tiny, fluffy cocoon, within which they develop into winged adults. Upon hatching young mealybugs, known, as crawlers, are extremely mobile and may disperse over large distances. Older nymphs are more or less sessile.

Adult female mealybugs are soft-bodied, elongated, oval insects with well-developed legs. They are about 3mm to 5mm long. Their body is usually covered with a mealy waxy secretion, often extended into lateral



Mealybug lifecycle

Female mealybugs on passionfruit leaf

Mealybug - United States National Collection of Scale Insects Photographs Archive, USDA Agricultural Research Service, Bugwood.org

Mealybug male - United States National Collection of Scale Insects Photographs Archive, USDA Agricultural Research Service, Bugwood.org

and terminal filaments. They are wingless and do not move unless disturbed. They usually remain clustered around the terminal shoots, leaves or fruits. They live for several months (depending on the species).

The short-lived males are up to 3mm long. Male adults have one pair of wings and several pairs of eyes but no mouthparts. Males fly about seeking females to mate with. In many species of mealybugs there are no males and females reproducing without mating. Some species lay eggs and others give birth to living young.

The most important species of mealybugs and their major host crops in Africa are:

- The cassava mealybug *(Phenacoccus manihoti)* attacks cassava
- The citrus mealybug *(Planococcus citri)* attacks a wide range of crops such as cocoa, bananas, tobacco and coffee and wild trees such as *Ceiba pentandra* and *Leucaena*
- The long-tailed mealybug *(Pseudococcus longispinus)* is widespread and common on many crops but it is usually not a serious pest. Major hosts plants of the long-tailed mealybug are citrus, taro, avocado, guava, eggplant and grapevine
- The mango mealybugs *(Rastrococcus iceryoides and R. invadens)* have been reported on a number of economically important plants, but there are reports

of economic damage only on mango and citrus
- The pineapple mealybug *(Dysmicoccus brevipes)* attacks pineapple and other crops including avocado, banana, celery, citrus, clover, cocoa, coconut, coffee, custard apple, figs, ginger, guava, maize, mango, oil palm, orchids, groundnut, peppers, plantain, potato and sugarcane
- The Kenya mealybug *(Planococcus kenyae)* attacks coffee and a large number of wild and cultivated plants including yam, pigeon pea, passion fruit, sugarcane and sweet potato
- The pink sugarcane mealybug *(Saccharicoccus sacchari)* is found primarily on sugarcane and its wild relatives *(Saccharum spp.)*. It has been recorded occasionally on sorghum, rice and other grasses
- The striped mealybug *(Ferrisia virgata)*. It is widespread and common on many crops but it is usually not a serious pest

3.6.21.3. The damage caused

Mealybugs damage plants by sucking sap from roots, tender leaves, petioles and fruit. They excrete honeydew on which sooty mould develops. Severely infested leaves turn yellow and gradually dry. Severe attack can result in shedding of leaves and inflorescences, reduced fruit setting and shedding of young fruit. The foliage and fruit may become covered with sticky honeydew, which serves as a medium for the growth of sooty moulds.

Honeydew, sooty mould and waxy deposits may cover leaves reducing photosynthetic efficiency and may lead to leaf drop. Contamination of fruit with honeydew and with sooty mould reduces its market value. The honeydew attracts ants, which collect the honey and indirectly protect mealybugs from natural enemies. Some mealybugs inject toxic substances while feeding causing deformation of the plant (e.g. the cassava mealybug). Some species transmit viruses (e.g. the pineapple mealybug).

Symptoms

Mealybug infestations of above-the-ground plant parts start with the appearance of crawlers (the first-instar nymphs) on the underside of the leaves on terminal shoots, stems and other plant parts. Heavy mealybug attack appears as white, waxy masses of mealybugs on stems, fruits and along the veins on the underside of leaves. Heavy infestations usually result in coating of adjacent stems, leaves and fruits with honeydew and sooty mould. Severely infested plants may wilt due to sap depletion; leaves turn yellow, gradually dry and ultimately fall off. Feeding on fruit results in discoloured, bumpy and scarred fruit, with low market value, or unacceptable for the fresh fruit market.

Female mealybugs

Mealybugs injecting toxic substance while feeding, cause plant deformation. This is the case of the cassava mealybug; feeding of this mealybug on cassava plants causes stunting, leaf distortion, shortening of the internodes and loss, dieback and weakening of stems used for crop propagation.

Mealybugs attacking roots, as is the case of the citrus mealybug on coffee and the pineapple mealybug, cause stunted roots, rotting of roots and subsequent wilting of the plants. Roots of coffee plants attacked by the citrus mealybug are often encased in a thick case of greenish-white fungal tissue; if the fungal coat is pealed off, the white mealybugs can be seen.

Affected plant stages

Seedling stage, vegetative growing stage, flowering stage and fruiting stage

Affected plant parts

Growing points, leaves, roots, stems and whole plant

Symptoms by affected plant part

Growing points: deadheart, abnormal forms.
Leaves: abnormal colours, abnormal forms, abnormal leaf fall, wilting, yellowed or dead, honeydew or sooty mould
Roots: reduced root system, fungal growth (coffee)
Stems: abnormal forms, abnormal growth, dieback
Fruits: scarring, discolouration, honeydew, sooty mould
Whole plant: wilting, plant dead, dieback, dwarfing

3.6.21.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

Early detection of mealybugs is necessary for effective control. Check plants for crawlers; pay special attention to the new growth (tender tissues), the undersides of leaves and around leaf joints.

Mealybugs can be controlled by:

- Removing mealybugs by rubbing or picking mealybugs from affected plants. This is practicable when infestation is low
- Pruning and destroying affected parts. This is particularly useful at the initial stage of infestation
- Removing and destroying heavily infested plants
- Spraying a steady stream of water (reasonably high pressure) on the host plant to knock-off mealybugs. Once on the ground, the fallen ones will be available to ground predators and this will also make their return to the plant difficult. Make sure that there are no ants tending mealybugs, otherwise they will be brought back to the host plants
- Ensuring soil fertility. In most cases healthy plants are able to withstand some mealybug attack. Moreover, improvement of soil fertility can enhance biological control activity as shown in the case of the cassava mealybug. It was observed that cassava grown in poor soils (pure sand and no mulch cover) had high mealybug infestations even after the release of the parasitic wasp *Apoanagyrus lopezi*. In experiments conducted in Benin, use of manure or other fertilisers resulted in a reduction in the cassava mealybug population. Improved plant nutrition resulted in the production of larger mealybugs, which in turn resulted in a higher proportion of female parasitic wasps with higher fertility levels. Mulch and fertiliser use also enhanced the antibiotic properties of cassava against mealybug infestation (Schulthess *et al.*, 1997; Neuenschwander, 2003)

3.6.21.5. Remedies

Biological pest control

Natural enemies

Mealybugs are attacked by numerous natural enemies, which usually keep them under control. Most common natural enemies include parasitic wasps, ladybirds, hover flies and lacewings. However, if many ants are present, or when broad-spectrum pesticides are used, they kill the natural enemies, mealybugs become a problem.

Mealybugs can also cause severe damage when introduced to new areas, where efficient natural enemies are absent. In this case, importation of natural enemies associated with the mealybugs in the area of origin (classical biological control), have usually given satisfactory control. Thus, several natural enemies, mainly parasitic wasps and ladybirds, were introduced from South America into Africa for control of the cassava mealybug. The most effective has been the parasitic wasp Apoanagyrus or Epidinocarsis lopezi, which has kept this mealybug at low levels, resulting on a significant reduction of yield losses in most areas in Africa.

Another example is the mango mealybug *Rastrococcus invadens*, which was brought under control in West and Central Africa by two parasitic wasps *(Gyranusoidea tebygi and Anagyrus mangicola)* introduced from India.

Conservation of natural enemies is important to reduce mealybug outbreaks. This can be done by:

- Limiting insecticidal sprays against other mealybugs or/and other pests and diseases and avoiding use of broad-spectrum pesticides
- Controlling ants to facilitate build-up of natural enemies. Ant control may be either indirect, by excluding ants from the tree (for example, by applying a barrier around the stems or trunks of the trees) or direct, by destroying the ant nests. However, it should also be taken into consideration that some ants may be beneficial as predators by deterring pests such as plant-feeding bugs
- Keeping flowering plants at the border of the crops or as companion plants within the crops may help to attract natural enemies

Bio-pesticides and physical methods

Neem

Neem products have a repellent effect on some mealybugs (Saxena, 2002). For example, a 1% hexane extract of neem seeds repelled the citrus mealybug in a choice test (Jacobson *et al*., 1978).

Young cassava mealybugs are sensitive to neem kernel water extract (NKWE). Thus, crawlers (first instar nymphs) of the cassava mealybug were repelled by leaves treated with a 10% neem kernel water extract and those that settled and started feeding died in the second instar. Treatment of cassava plants with neem extracts (NKWE) at concentration of between 1% and 25% provided good protection against the cassava mealybug. However, some phytotoxicity manifested as yellow spots on the leaves, was observed on plants treated with neem extracts. Phytotoxic damage was slight in plants treated with lower concentrations (1% and 10%), but plants treated with neem extracts at 25% showed severe phytotoxic symptoms on some of the leaves (Mourier, 1997).

Soap spray

When necessary, spray with soapy solutions (1% to 2%) or insecticidal soaps. Spraying with a soap and water solution is reported to control mealybugs. Whenever possible, spray only infested plants (spot spraying).

Oils

Oils such as vegetable oils (e. g. rape oil), neem oil and mineral oils are useful for control of mealybugs.

Application of soap and oil: Good spray coverage and good timing is important when using soapy solutions and oils. To be effective they must come in contact with the mealybugs. Crawlers are the easiest to kill, since they are more susceptible and are more exposed than eggs, older nymphs and adults. As they grow, the wax covering their bodies becomes thicker, rendering them more resistant to insecticides. Use soapy solutions and oils with caution. These products may be toxic to some plants causing discolouration or burning of foliage. Prior to applying them extensively, apply to a small, inconspicuous branch or to a few plants and check for adverse reactions after 48 hours. Apply them when the air temperature is cool. Make sure your plants were watered well the day before you apply your control - never spray wilted plants.

3.6.22. Root-knot nematodes

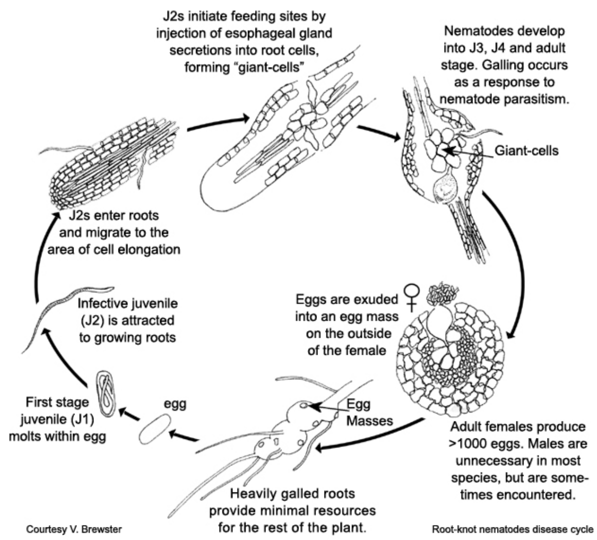
3.6.22.1. Scientific and common names

Meloidogyne spp. (M. incognita, M. hapla, M. javanica, M. arenaria)
Eelworms

3.6.22.2. What it is

The root-knot nematode species, *M. incognita*, is the most widespread and probably the most serious plant parasitic nematode pest of tropical and subtropical regions throughout the world. It occurs as a pest on a very wide range of crops.

There are four species of root-knot nematodes *(M. arenaria, M. hapla, M. incognita and M. javanica)* that are capable of attacking vegetables. Important environmental factors that influence the development of *Meloidogyne* are moist soils and relatively warm temperatures. Some plant penetration by root-knot nematodes occurs between 10° and 35°C, with the optimum at about 27°C depending on the species. No eggs are laid at temperatures lower than 14.2°C or higher than 31.7°C. Under average conditions a female produces 300 to 800 eggs. A new generation can arise within 25 days, but under less favourable conditions, the time may be prolonged to 30 to 40 days. All species, with the exception of *M. hapla* are killed by freezing.



Root-knot nematode life cycle

Root-knot nematodes measure about 0.5mm to 1.5mm in length.

Juveniles (young nematodes) penetrate the root tips and occasionally invade roots in the zone of root elongation. Invaded nematodes initiate the development of giant cells in the root tissues and galling of roots occurs.

Root knot nematodes are soil inhabitants. They are spread by transplanting infested seedlings, or from soil washed down slopes or sticking to farm implements and farm workers. They may also be spread by irrigation water.

The disease is most serious on light, sandy soils and in furrow irrigated areas. Attack by nematodes may greatly increase the severity of bacterial, *Fusarium* and *Verticillium* wilt diseases.

Conditions that favour development:

- Infected volunteer plants
- Monocultures
- Weeds in fields
- Warm temperatures and moist but well-aerated sandy soils
- Continuous growing of susceptible crops (no rotation)

Root-knot nematodes affect a wide range of crops, particularly vegetables. *M. incognita* is a major economic pest of food legumes in the tropics and subtropics. The common bean *(Phaseolus vulgaris)* is very badly damaged by *Meloidogyne* species in the tropics. Cowpea *(Vigna unguiculata)* is another very susceptible host crop of *M. incognita*. Many vegetables crops are susceptible to the nematode particularly tomato, aubergine, okra, cucumber, melon, carrot, gourds, lettuce and peppers. Table 1 shows susceptibility of various commonly grown crops to root-knot nematodes.

3.6.22.3. The damage caused

Symptoms

Affected plants are stunted and yellow and have a tendency to wilt in hot weather. Very heavily infested plants are killed. Affected plants appear in patches. If infested plants are pulled from the soil, the roots are severely distorted, swollen and have lumps known as galls or root knots. The galls range in size from smaller than a pinhead to 25mm or more in diameter.

Root-knot nematode

Root-knot nematode damage (Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org)

Root-knot nematode on sweet potato - Charles Averre, North Carolina State University, Bugwood.org

Affected plant stages

Flowering stage, fruiting stage, seedling stage and vegetative growing stage

Affected plant parts

Leaves, roots and whole plant

Symptoms on affected plant part

Leaves: wilting
Roots: galls; reduced root system; swollen roots
Whole plant: dwarfing; wilting

Affected plants appear in patches. Estimates of vegetable crop losses due to *Meloidogyne* species, mainly *M. incognita and M. javanica*, have ranged from 17% to 20% for aubergine *(Solanum melongena)*, 18% to 33% for melon and 24% to 38% for tomato.

Losses of potatoes due to *Meloidogyne* species, mainly *M. incognita*, are estimated at 25% or more.

3.6.22.4. Cultural practices to prevent its occurrence

Cultural practices

Prevention and control

- Do not locate seedbeds where vegetables have been grown previously. After preparation of the seedbed, burn the topsoil using dry leaves or other waste plant material
- Solarise seedbeds if possible
- Use biofumigation where possible. Different mustards *(e.g. Brassica juncea var. integrifolia or Brassica juncea var. juncea)* should be used as intercrop on infested fields. As soon as mustards are flowering they are mulched and incorporated into the soil. While incorporated plant parts are decomposing in a moist soil, nematicidal compounds of this decomposing process do kill nematodes. Two weeks after incorporating plant material into the soil a new crop can be planted or sown
- Maintain high levels of organic matter (manure and compost) in the soil
- Incorporate neem cake powder into the soil if it is available
- Fields should be ploughed deep and then followed by a dry fallow
- Uproot entire plants from the field after harvest and destroy crop debris

Crop rotation

Rotate with onions, baby corn, sweet corn, maize, millet, sorghum, sesame, cassava or Sudan grass.

A rotation system called "STRong" is recommended for management of root-knot nematodes. The system was developed by, African Farmers' Organic Research and Training (AfFOResT), a NGO in Zimbabwe. It involves planting a rotation of a susceptible crop (e.g. tomatoes), followed by a tolerant crop (e.g. cabbage) and then a resistant crop (e.g. onions) before a return to a susceptible crop (e.g. tomatoes). Crop susceptibility of various commonly crops is given in Table 1.

Table 1. Crop susceptibility to root-knot nematodes (after AfFOResT)

Susceptible	Tolerant	Resistant
Bambara nut	Brassicas	Cassava
Beans	Chilli pepper	Garlic
Beetroot	Radish	Leek
Carrot	Sweet potato	Maize
Celery	Turnip	Millet
Cowpea		Rhodes grass
Cucumber		Sesame
Eggplant		Sorghum
Gourd		Sudan grass
Irish potato		Sweet corn
Lettuce		
Melon		
Okra		
Parsley		
Peas		
Pumpkin		
Squash		
Sweet pepper		
Swiss chard		
Tomato		

(*Source:* Dobson *et al*., 2002)

Use trap crops such as marigold (Tagetes spp.) and Indian mustard. (A trap crop is a crop planted to attract a pest and is then destroyed together with the pest). Mixed cropping with marigold can also minimise root-knot nematode damage.

Resistant varieties
Use resistant tomato varieties (e.g. 'Caracas', 'Kentom', 'Meru', 'Piersol', 'Roma VFN', 'Tengeru 97', 'Zest F1', 'Star 9001', 'Star 9003'). Tomato varieties carrying 'VFN' label are tolerant to root-knot nematodes. Most of these varieties are commercially available in the region.

3.6.22.5. Remedies
Nematodes have been successfully combatted with the application of beneficial microbes, such as EM (Effective Microorganisms) and IM (Indigenous Microorganisms). Ideally the fields are inoculated with beneficial microbes before the crop is planted as well. For this to be effective the soil has to have good organic matter content as food for the microbes.

For more information see chapter 5. Common control methods for pests & diseases

3.6.23. Spotted stemborer
3.6.23.1. Scientific and common names

Chilo partellus (Swinhoe)
Spotted sorghum stemborer, Spotted stalk borer

3.6.23.2. What it is
The spotted stemborer is one of the most notorious stemborers in East and Southern Africa. This pest is not native to Africa, but was accidentally introduced from Asia. It is essentially a pest of hot lowland areas and it is seldom found above an altitude of 1 500m. Since its appearance on the African continent, it has continuously spread to the warm, low-altitude regions of eastern and southern Africa. It is now the most economically destructive stemborer in many areas. In Africa, the spotted stemborer is a major pest of maize, sorghum and pearl millet. It has also been found in wild grasses and mainly wild sorghum.

Eggs of the spotted stemborer are flat and oval, creamy-white and about 0.8mm long. They are laid in overlapping batches on the underside of a leaf near the midrib. They hatch after 4 to 10 days.

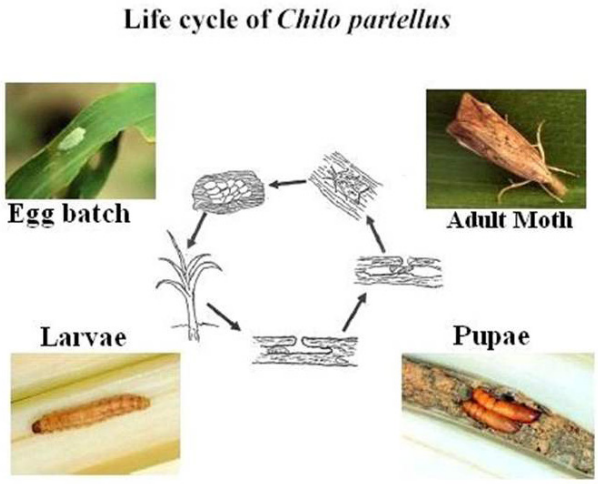
Caterpillars are up to 25mm long when fully grown, with a prominent reddish-brown head. The body is creamy-white to yellowish-brown, with four purple-brown longitudinal stripes and usually with very conspicuous dark-brown spots along the back, which give them a spotted appearance. Young caterpillars initially feed in the leaf whorl. Older caterpillars tunnel into stems, eating out extensive galleries.
In warm conditions, larval development is completed in about 15 to 20 days. Caterpillars pupate in damaged stems.

Spotted stemborer caterpillar

Pupae are up to 15mm long, slender, shiny and light yellow-brown to dark red-brown in colour. Adults emerge 5 to 12 days after pupation.

Adults are relatively small moths with wing lengths ranging from 7mm to 17mm and a wingspan of 20mm to 25mm. The forewings are dull, generally light yellow-brown with some darker scale patterns. The hind wings are white. Adults emerge from pupae in the late afternoon or early evening. They are active at night and rest on plants and plant debris during the day. They are seldom seen, unless disturbed.

Spotted stemborer moth



Chilo partellus lifecycle

The whole life cycle takes about 3 to 4 weeks, sometimes longer in colder months and shorter in hot months. Five or more successive generations may develop in favourable conditions. In regions where there is sufficient water and an abundance of host plants, *Chilo partellus* normally develops continuously all year-round. In other regions with long dry periods in winter or in summer, the spotted stemborer, as with many other cereal stemborers, pass the winter or dry season as fully-grown caterpillars in a resting period (diapause) in stems and stubbles in the field. They may remain inactive for up to six months, before pupating and completing their development early in the following growing season.

In Southern Africa, the spotted stemborer diapauses for several months in the dry season. However, populations without a resting period are reported in the coastal areas. In the coastal areas, in periods between cropping seasons, some stemborers diapause in maize stubble, while others remain active, and feed in wild grasses such as wild sorghum.

3.6.23.3. The damage caused

Young caterpillars of the spotted stemborer feed on tender leaves of the plants. They later feed at the growing point into the stem. Badly attacked plants dry-up entirely or partly, showing the so-called 'dead heart' symptom. Plants that are attacked during their early growth stages are stunted in growth and the ears are poorly developed. Stem tunnelling by older caterpillars interferes with transference of nutrients to the grain. Stemborer damage results in plant stunting, lodging, stem breakage and direct damage to ears. Infestations by stemborers increase the incidence and severity of stalk rots and may increase the contamination of the grains with toxin-producing fungi like *Aspergillus flavus.*

Symptoms

Leaves show irregular scars, holes and windows caused by the feeding of young caterpillars. Badly attacked plants, especially young ones dry-up entirely or partly showing the so-called 'dead heart' symptom, due to the death of central leaves. The longitudinal dissection of the stalks will reveal the caterpillars. In older plants, the upper part of the stem usually dies due to the boring of the caterpillars in the stem. Older caterpillars tunnel extensively in stems and in maize cobs, weakening the stems, which may then break. Damage to inflorescences may interfere with grain formation, causing chaffy heads in sorghum. Similar symptoms are produced by other species of cereal stemborer.

Spotted stemborer damage - caterpillar

Spotted stemborer caterpillar on maize cob

Spotted stemborer damage on young maize

Affected Plant Stages

All stages

Affected Plant Parts

Ear/head, growing points, leaves, stems

Symptoms by affected plant part

Ear/head: internal feeding; external feeding.
Growing points: internal feeding; boring; dead heart
Leaves: external feeding; internal feeding
Stems: internal feeding; deadheart

3.6.23.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

Infestations of stemborers are detected by walking through young crops and looking for characteristic feeding marks on funnel leaves, the presence of dead hearts and holes in tunneled stems. Samples of affected stems are then dissected to retrieve caterpillars and pupae.

As other stemborers cause similar symptoms, retrieval of caterpillars or pupae and confirmation of their identity by rearing adults for identification by a taxonomic specialist is essential to ensure a correct diagnosis.

The presence of this species in older crops and in crop residues may be detected by taking random samples of stems or stools for dissection.

Crop sanitation

Practise good crop hygiene, this includes the destruction of crop residues such asstems and stubbles. Remove volunteer crop plants and/or alternative hosts. This reduces carry-over of stemborers from one growing season to the next and will help to limit the most damaging attacks on young crops early in the growing season.

Disease avoidance

Manipulating sowing dates may also be useful in avoiding periods of peak adult activity. However, this is not practical in situations where lack of water is a major constraint as farmers often plant after first rains.

Improvement of soil fertility

Studies on several stemborers in Africa show that soil nutrient levels, such as nitrogen, greatly influenced the nutritional status of the plant and the plant's tolerance to stemborer attack. Although an increase in nitrogen is related to higher pest loads and tunnel damage, there is also an increase in plant vigour with a net benefit to the plant reflected in lower yield losses (Setamu *et al*., 1995).

Trials done in Tanzania to evaluate the effect of nitrogen fertilisation (0, 50, 70, 100kg N/ha) on pest abundance, plant damage and yield loss of maize due to stemborers showed the beneficial effect of nitrogen on the maize plant's abilities to compensate for damage by the spotted stemborer. Yield loss decreased with an increase in nitrogen application and the effect was stronger under higher rather than lower borer infestation levels (ICIPE, 2005; Mgoo *et al*., 2006).

Intercropping and habitat management

The importance of plant biodiversity in maize agro-ecosystems for reducing borer's infestation on that crop has been recognised in sub-Saharan Africa. Studies have shown that intercropping maize with cowpea is an effective way of reducing damage by the spotted stemborer caterpillars migrating from neighbouring plants. The effect is variable if the crop to be protected is not planted after the companion crops.

Intercropping maize with molasses grass *(Melinis minutiflora)*, which is a non-host for stemborers, significantly reduced stemborer infestation on maize. A significant increase of parasitism of stemborers by the wasp (*Cotesia sesamiae)* was also observed. Molasses grass produces volatile agents, which repel stemborers but attract the parasitic wasp. In addition, the molasses grass is an effective cover crop and provides good fodder for livestock. Greenleaf desmodium *(Desmodium intortum)* repels egg-laying stemborer moths and in addition, when intercropped with maize, suppresses and eliminates *Striga*.

Trap crops

Planting an outer encircling row of some highly preferred hosts as trap plants is another useful diversionary tactic for management of stemborers. Examples of trap plants are Napier grass *(Pennisetum purpureum)* and Sudan grass *(Sorghum vulgare sudanense)*, and are common fodder plants in Africa. Napier grass is highly attractive to egg laying moths, but only few caterpillars complete their lifecycles, because when they enter the stem the plant produces a gummy substance that kills the caterpillars. Sudan grass provides natural control of stemborers by acting as a trap crop (attracting moths) and as a reservoir for its natural enemies.

"Push-Pull"- Strategy

A simple habitat management strategy has been developed combining the use of intercropping and trap crop systems. The strategy is known as "Push-Pull", whereby farmers use Napier grass and *Desmodium* legume (silverleaf and greenleaf desmodium) as intercrops. *See detailed description at the beginning of the manual.*

3.6.23.5. Remedies

Natural enemies

Two parasitic wasps that attack stemborers were introduced from Asia into Africa: *Cotesia flavipes* and *Xanthopimpla stemmator.*

Cotesia flavipes is a small wasp that attacks caterpillars of the spotted stemborer in Asia.

This wasp was imported, mass reared in the 1990's and subsequently released in East and southern Africa. *Cotesia flavipes* locates the stemborers, while they are feeding inside the plant stems. The wasp lays about 40 eggs into a stemborer. Upon hatching, the larvae of the parasitic wasp feed internally in the stemborer and then exit the stemborer to spin cocoons. This parasitic wasp is now established in several countries (Kenya, Tanzania, Mozambique, Uganda, Ethiopia, Zambia, Zimbabwe, Zanzibar, Malawi, Somalia) (Omwega et al. 2006; Kfir et al, 2002). Studies of the impact of this parasitic wasp in coastal Kenya showed that it has caused a 70% decrease in stemborer densities.

Xanthopimpla stemmator, a wasp attacking pupa of stemborers, has been recently imported and released in several countries. Local natural enemies such as earwigs and ants are also important for control of stemborers, including the spotted stemborer.

Bio-pesticides and physical methods

Neem

Neem products are effective for control of stemborers, including the spotted stalkborer. It is recommended that a small amount of neem powder (ground neem seeds) mixed with dry clay or sawdust at a rate of 1:1 is placed in the funnel of the plant.

One kilogram of powder should be sufficient to treat 1 500 to 2 000 plants. Using this method, rain water dissolves the active substances in neem powder as it gathers in the funnel and washes out the powder. Where rainfall is irregular, a liquid neem seed extract can be sprayed into the funnel.

The treatment should be repeated every 8 to 10 days during the sensitive growing phase. Thus, roughly three treatments are required per crop.

This recommendation applies only for young plants before flowering and not for older plants.

A mixture of ground neem kernels and sawdust (1:1) applied as granules at weekly and biweekly intervals reduced the number of maize plants attacked by the spotted stemborer by 60% and 40% respectively in field trials.

In experiments in Somalia, pulverised neem kernel and kernel cake (0.5g and 1g per plant) alone or a mixture with clay, markedly reduced stalk borer damage and increased the yield in comparison with the check plots by over 100% (Hellpap, 1995).

3.6.24. Storage pests – Weevils, Grain Borers, Bruchids, Khapra Beetles

3.6.24.1. Scientific and common names

Various, see below

3.6.24.2. What it is

One of the main causes of food insufficiency in East Africa is the high prevalence of storage pests. Grains, dry legume seeds and tubers are excellent food not only for humans but many other creatures too. Food stores are excellent breeding sites for all those pests. A farmer has to take adequate measures regarding food storage to conserve his/her crops and to be able to feed the household even during longer droughts.

The main storage pests, apart from rodents, are beetles and moths.

Some pests such as grain borers, weevils and angoumois grain moths are able to feed on whole, healthy grains and are considered primary pests. Secondary pests such as flour beetles can attack only broken grain, moist and – and therefore soft – grain, grain damaged by primary pests or processed products such as flour.

Contamination by fungi also causes direct losses and poses a threat to human and animal health by producing poisons known as mycotoxins, which contaminate food and feed.

Beetles: Weevils, Grain Borers, Bruchids, Khapra Beetles

The main beetle pests of storage are bruchids (e.g. cowpea seed beetles and bean bruchid), grain borers (e.g. the larger and the lesser grain borers), weevils (e.g. grain weevils), flour beetles, Khapra beetles and dried fruit beetles.

The larvae and some adult beetles feed in the seeds and grain, leaving them full of small holes. Sometimes a fine dust is found around the holes, which is the beetle excrement. Beetle damage renders grains and seeds unsuitable for human and, in case of heavy attack, even animal consumption.

Cowpea bruchids *(Callosobruchus spp.)* are the most common and widespread insect pests in storage. Adults are 2 to 3.5mm long and are major pests of pulses such as cowpeas, pigeon peas, soybean, green gram and lentils. They attack both pods in the field and seeds in storage and nearly mature and dried pods. Infested stored seeds can be recognised by the round exit holes and the white eggs on the seed surface. Post-harvest losses are highly variable, but losses can exceed 90%.

What to do:

Pods should be harvested as soon as they mature and the seeds sun dried before they are stored in clean beetle-proof containers. A coating of edible oils or of inert clay can prevent further development of bruchids in the stored seeds. Some farmers in East Africa use wood ash in grain stored for food or seed for planting, or chillies or smoke from cooking fire to preserve seeds for planting. Other farmers store un-threshed pods as a strategy to minimise grain damage by bruchids (Minja et al. 1999).

Bean bruchid

This beetle, also known as the dry bean weevil, is about 3 to 5mm long, oval in shape, grey and reddish brown with yellowish and dark patches of hairs on the wing cases. The wing cases are short and do not cover the abdomen completely.

This beetle is a major pest of beans. Attacks by this beetle often start in the field with female beetles laying eggs on the ripening pods of the crop or among stored beans. The larvae bore the way into the seed and feed inside. The presence of mature larvae or pupae can be recognised by the small circular windows on the bean seeds. The life cycle is completed inside the seed and the adult beetle emerges by pushing the window, which falls off leaving a neat round hole of about 2mm in diameter.

Cowpea beetle

Bean bruchid on soybean

What to do:
Intercropping maize with cowpeas and not harvesting crops late significantly reduced infestation by the bean bruchid (Acanthoscelides obtectus) and cowpea bruchids in Kenya (Olubayo and Port, 1997).

The larger grain borer
The larger grain borer is a serious pest of stored maize and dried cassava roots and will attack maize on the cob, both before and after harvest.

Larger grain borer

What to do:
Use botanicals or plant parts to protect stored cassava. There are reports in Kenya, that the larger grain borer can be effectively repelled by storing cassava or grains with a fairly large amount of dried lantana or eucalyptus leaves (Personal communication, field officer of Meru herbs). Neem is also reported to be effective.

The lesser grain borer
This is a tiny beetle (2mm to 3mm long) with a slim and cylindrical shape and red-brown to black in colour. The thorax bears rows of teeth on its upper front edge and the head is turned down underneath the thorax so that it cannot be seen from above. Eggs are laid loosely among the cereal grains. The larvae are mobile. Both larvae and adult bore through the stored produce usually causing characteristic round tunnels of up to 1mm in diameter.

Lesser grain borer on wheat grains

In later stages of infestation these beetles may also hollow out the grains. Pupation usually takes place within the eaten grain. The lesser grain borer is primarily a pest of cereal grains, other seeds, cereal products and dried cassava. It will be controlled by any method that controls the larger grain borer.

Grain weevils *(Sitophilus spp.)*
The adults are small (2.5mm to 4.0mm long), brown weevils with a long, narrow snout. Female lays eggs inside the grain. The larva (grub) lives and feeds inside the grain hollowing it out. The adult attacks whole or damaged grains causing irregularly shaped holes. Grain weevils attack grains either in the field before harvest or in the store.

The rice weevil *(Sitophilus oryzae)*
Is a major pest of rice, maize and other cereals in store.

Rice weevil

Flour beetles *(Tribolium castaneum, T. confusum)*
The adults are elongated beetles, 3mm to 4mm long, red brown to dark brown in colour. The wing cases are marked with finely punctured lines. Larvae and adults are secondary pests and attack cereals and cereal products, groundnuts, nuts, spices, coffee, cocoa, dried fruits and occasionally pulses. Infestation leads to persistent unpleasant odours of the products.

Khapra beetle *(Trogoderma granarium)*
The adults are oval beetles, 2mm to 3mm long, dark brown in colour and often have blurry reddish markings. The larvae are very hairy. They are common in hot dry areas. Damage is done only by larvae feeding on cereal grains and products, groundnuts, oilseed cakes, nuts, pulses, etc.

Dried fruit beetles *(Carpophilus spp.)*
They are slightly flattened ovate to oblong beetles, 2mm to 5mm in length. The wing cases are short, leaving part of the abdomen exposed. They are light brown to black in colour, but several species have yellow or red markings on the wing cases. They are secondary pests; presence of these beetles is an indicator of damp, mouldy conditions. Adults and larvae cause damage on poorly dried cereal grains, cocoa, copra, oilseeds, dried fruit, vegetables, herbs and mouldy produce.

Moths

The potato tuber moth (Phthorimaea operculella)
This moth is the most serious pest of potatoes in the region. It occurs in Africa wherever potatoes are grown and it also attacks tobacco, eggplants and tomatoes.

Caterpillars of the potato tuber moth are up to 12mm long and feed as leafminers, causing silver blotches on leaves and bore into the petiole or a young shoot or main leaf vein and later into the tuber. This causes wilting of plants. When eggs are laid on tubers, caterpillars begin feeding on the tubers immediately upon hatching, making long irregular black tunnels, which are filled with excreta (faeces), where disease-causing microorganisms grow.

Major damage is caused by caterpillars burrowing in the tubers. Infestations start in the field. The pest is transferred with the harvested tubers to the potato store, where it can reproduce and infest other tubers. This may lead to total destruction of the stored crop.

Potato tuber moth damage

Potato tuber moth pupae on potato tuber

Control
Natural enemies are important for natural control of the potato tuber moth. However, in many cases control by local natural enemies is not satisfactory. Therefore, several parasitic wasps, native from South America, the area

of origin of the pest, have been introduced to several countries in Africa. These wasps have provided effective control of the pests in several countries in southern and East Africa.

Cultural methods (e.g. ridging, use of healthy seed tubers) and Bio-pesticides (e.g. Bt, neem, lantana) as described below are also important for managing this pest.

Remedies

What to do:

- Farmer experience: Some farmers had tested mixing dried lantana leaves with stored maize and beans – the samples had stayed for over a year without getting attacked by storage pests
- Lantana leaves protect maize and cowpeas from storage pests

Lantana leaves protecting maize and cowpeas

- Use healthy, clean seed, since infested seed tubers are the main cause of re-infestation in the field
- Avoid planting in rough soil. Plant as deeply as possible (10cm deep) and ridge at least three times during the growing season. Experiments in Sudan showed that a practice by farmers of increasing the sowing depth from 2.5cm to 7.6cm, significantly reduced damage by the cutworms and the potato tuber moth and resulted in an increase of 3.7t/ha in marketable yield (Siddig, 1987)
- Compact hilling is a very important remedy that can be used to prevent moths from reaching the tubers to lay eggs. For caterpillars it would also be difficult to reach the tubers because they will not be able to penetrate so deep into the soil and similarly, emerging moths will be killed because of the depth of the soil from which they will have to surface
- Provide enough water to prevent soil cracks
- Mulch the plants with straw and/ or with leaves. Mulching with neem leaves during the last 4 weeks before harvest significantly reduced insect damage in Sudan (Ali, 1993)
- Intercrop potatoes with hot pepper, onions or peas
- Harvest the crop immediately as it matures, as tubers left in fields for long periods are highly susceptible to infestation
- At harvesting, ensure that the tubers are not exposed to moths before they are properly protected in the store. All harvested tubers have to be bagged and removed before late afternoon every day
- Destroy all infested potatoes immediately and remove all plant residues from the field. Caterpillars pupate in the tubers and dry stems left in the field
- Destroy all volunteer potato plants before planting new potato crops
- Use alternative pesticides to protect potatoes in store. Neem can be applied to reduce damage by the potato tuber moth. For instance, in India four months'protection was achieved when harvested potatoes and the covering material was sprayed with 5% and 10% enriched neem seed extract (Saxena, 1995). In Sudan spraying neem seed and leaf extracts (1kg/40l water) and

then placing tubers in jute sacks reduced post-harvest losses by the potato tuber moth compared with traditional methods such as leaving the tuber unprotected or covering them with banana leaves only (Siddig, 1987). Salem (1991) showed that a neem seed extract was effective for control of the potato tuber moth on potatoes in a store in Egypt. Storage loss after 6 months in potatoes treated with 100ppm neem oil was 25% (compared with 10% with the insecticide carbaryl). Adults from larvae treated with neem oil were deformed. Work in Yemen confirmed the beneficial effect of neem. Neem oil and sunflower oil halted the development of caterpillars of the potato tuber moth in storage. However, caution is needed since the oil seemed to interfere with potato respiration, leaving the potatoes very soft with dark tissue (Kroschel, 1995)

- A *Bt (Bacillus thuringiensis)* preparation in powder form mixed with fine sand (1:25) and dusted over the crop was very effective in controlling this pest in the store in Yemen and Kenya (Kroschel, 1995). Tuber infestation was also reduced by bedding the potatoes in the leaves of the Peruvian pepper tree *(Schinus molle)* and *Eucalyptus sp.* (Kroschel, 1995)
- Where this pest is present, potatoes should be stored in layers with branches of lantana (Kenya Institute Organic Farming), which repels tuber moth but does not actually kill it. Also application of plenty of wood ash or diatomite earth may prevent rapid buildup of tuber moth

Grain moths

Angoumois grain moth (Sitotroga cerealella)

The Angoumois grain moth is small (about 1cm long with a wing span of 10mm to 18mm), yellowish or straw-coloured and has a fringe along the posterior margins of the wings. They can be observed flying around infested stores.

Angumois grain moth on maize

Female moths lay ovoid and pinkish eggs at night in clumps on the outside of cereal grains, in cracks, grooves or holes made by other insects. Eggs are initially white turning red near hatching. The larvae are caterpillars of dirty white colour and about 8mm long when fully grown. Caterpillars penetrate into and feed inside whole grains. They prepare a round exit hole for the moth, leaving the outer seed wall only partially cut as a flap over the hole, resembling a trap door.

The adult pushes its way out through this "window" leaving the trap door hinged to the grain. Infested grains can be recognised by the presence of these small windows. The adult lifespan may be up to 15 days and one female can lay over 100 eggs.

They are pests of whole cereal grains like sorghum, maize and wheat. Damage is similar to that caused by weevils. This moth may also infest the crop in the field prior to harvest and damage can reach serious levels, before the grains are stored.

Storage moths or tropical warehouse moth

(Ephestia cautella, Corcyra cephalonica, Plodia interpunctella)

The main storage moths are the tropical warehouse moth *(Ephestia cautella)*, the rice moth *(Corcyra cephalonica)* and the Indian meal moth *(Plodia interpunctella)*. These storage moths are small (15mm to 20mm wingspan), and greyish brown in colour with an indistinct pattern.

Storage moth

The Indian meal moth is distinctive with the outer half of the forewings a coppery-red, separated from the creamy inner half by dark grey bands.

Female moths lay eggs through holes in the bags. Larvae are elongated whitish caterpillars about 2cm long. They feed on the seed germ, moving about freely in the stored foodstuff. They cause extensive damage in cereal flours and other milled products, but also in whole grains, mainly feeding on the germ. They also attack nuts, groundnuts, dry fruit, cocoa, copra and other foodstuff. The dense white cocoons of the pupae are often seen attached to the bag surfaces. Infestations are characterised by aggregations of kernels, frass, cocoon and dirt caused by webbing, which contaminates the foodstuff, reducing its quality.

Fungi

Storage fungi include species of Aspergillus and Penicilium.

Storage fungi require a relative humidity of at least 65%, which is equivalent to equilibrium moisture content of 13% in cereal grain. Storage fungi grow at temperatures of between 10° to 40°C. Infection with certain species of fungi may already occur in the field, reducing the storage life of grains considerably.

Infection with storage fungi can cause:

- Loss of nutrients
- Discolouration of the grain
- Reduction of germination capacity
- Caking of grains
- Increase in the temperature of the stored goods up to spontaneous combustion.
- Mouldy smell and taste
- Production of mycotoxins. These are toxic substances produced by various fungi under certain conditions, which remain in the stored product as residues. They are highly poisonous to both humans and animals. The best-known mycotoxins are aflatoxin, ochratoxin, patulin and citrin. Aflatoxins, which are produced by *Aspergilum flavus*. They are regarded as very dangerous substances that can cause liver cancer

Damage caused by fungi is often neglected until it has reached an advanced stage. However, it is very important to prevent growth of fungi, since it is the only way of avoiding mycotoxins. Mycotoxins are very stable and cannot be destroyed by boiling, pressing and processing. This means that infected produce has to be destroyed. Mycotoxins can be found in the stored product as soon as 24 hours after infection with fungus.

To prevent contamination by fungi, the produce must be properly dried and any source of moisture in the store should be avoided.

Storing Seeds and Grains – Principles of Preventative Storage Protection

1. Choice of variety and selection of healthy seeds

Select the most suitable seeds for planting. Indigenous seeds have been developed for hundreds of generations and are well adapted to the areas where they are grown, whereas some modern varieties are higher yielding, but may be more susceptible to pests. There is a widespread perception that modern, high-yielding varieties of maize may be more susceptible to storage pests. These varieties often have open cob husks, allowing insects and birds to easily attack maize in the field, whereas some of the traditional varieties have closed husks, thus effectively protecting the crop from insect attack. The same has been observed with some sorghum varieties. Therefore, the increased yield offered by some varieties should be weighed against the susceptibility to storage pests, the expected period of storage and the price to be expected for grain of a particular damage level. Efforts are on-going to develop high yield varieties with resistance to storage pests.

Selecting the best seeds for the following year's planting and avoid using damaged and sick looking seeds.

2. Choosing harvest time

If planting and harvesting is planned so that harvest falls in the dry season, there are no special problems with drying the crop. Care should be taken when cultivating new, high yielding and early ripening varieties, since the harvest may fall in the wetter part of the year and this may create problems with storage.

Some storage pests such as bean beetles, cowpea bruchids, the larger grain borer and some moths, infest beans and grains in the field only when the crop is almost dry. Timely harvest can therefore ensure that these pests are not carried into the store along with the beans or grain. Thus, timely harvesting –and avoiding late harvesting - can significantly reduce infestation by the bean bruchid and cowpea bruchids. As a rule, do not leave crops in the field when they are ready for harvest and this increases the chances of infestation by some storage pests.

3. Drying

Drying is an important procedure in storage protection. It prevents seed from germinating and prevents attack by fungi. Some fungi can cause cracking of seed thereby making the seeds more susceptible to pest attack. All seed must be dried to between 12% and 13% moisture content in order to be stored safely. To make sure the seed is properly dried put one seed or kernel in the mouth and chew. If it cannot easily be cracked it is dry enough - if it crushes between the teeth it is not dry enough. This is known as the tooth test.

Heat used for drying the produce will also kill larvae and chase away adults of insect storage pests. Care should be taken to avoid overheating, since excessive heat can damage seed or grains. Care should be taken not to exceed the following temperatures:
beans: 35°C; seeds: 43°C; cereals: 60°C.

The following methods of drying are alternatives:

- Seed can be spread out in the sun on a hard, clean surface to dry for several days in dry weather, until a seed cannot be bitten into when putting it in the mouth. The thickness of the layers of cobs, panicles, pods or grains must not exceed 5cm and the seed must be turned regularly in order to ensure good and even aeration. In the evening, the produce must be put in a pile and covered
- Simple driers. Several designs of solar driers are available

4. Sorting and cleaning the produce

Check whether the produce is infested by taking samples. Pay particular attention to cracks and gaps where insects may hide. If the produce is infested, ensure it is stored separately (quarantined) and treated in order to prevent the pests from infesting clean produce. In cases of heavy infestation, discard the produce. In case the produce is slightly attacked, heating to no more than 50°C can kill moths and weevils; use a thermometer, as heating to any higher temperature will destroy the germination capacity the seeds.

Removal of infested grains or cobs and pests can also be done by hand, sieving, winnowing or moving the grain (shaking, re-stacking). When separating the pests from the stored product, ensure that the pests that are removed are killed to avoid re-infestation.

5. Store location

Site stores away from any potential source of infestation. The grain and tuber moths are good flyers and adults from infested stores often infest growing crops in the field. Separating stores from fields may help to reduce attack.

6. Characteristic of store

A good seed store must be airy, shady, cool and dry. Temperature variations should be as small as possible, because it encourages condensation of water, which promotes fungal development.

Crops in the store should be protected against dampness rising from the ground and the site should be safe from flooding in the rainy season. The roof should have no leaks. Keep the temperature and humidity as low as possible (perform controlled ventilation). There are indications that storing grain in a dry place may help reduce infestation of grain moths.

Prevent pest entry by sealing the store (windows, doors, ventilation facilities) with insect-proof gauze. In Malawi, plastering stores with mud to reduce water uptake was found to be effective (Golob and Muwalo, 1984).

Hermetic, airtight storage at low humidity gives good protection against storage pests. However, to avoid mould growth, care should be taken to ensure that the produce is dry. This is particularly applicable for long-term storage in warm, dry areas. It is advisable however, not to store seed grain for more than a few months. In conditions where the relative humidity is high, airtight storage is not recommended due to the risk of mould growth.

Hermetic storage is useful for storing small amounts of seeds or grains (e.g. to be used for replanting); they can be stored in a strong airtight container with a tight fitting lid (glass, ceramic, strong plastic, can be useful). Ceramic pots that do not have lids must be covered very carefully or topped up with dry soot, ashes or fine dry soil.

7. Storage hygiene

Always keep the store and its surroundings clean. It has been said: "the most important, economic and effective tool for storage hygiene is the broom". Before newly harvested crops are stored, the store should be carefully prepared well ahead of time. Old stored products should be removed and the room completely cleaned. The whole building should be well aired and if possible fumigated or disinfected (see store fumigation and disinfection below). The walls, roof and floor should be both watertight and rat proof and small holes and cracks, which are potential breeding places for storage insects, should be sealed.

8. Inspecting the store

Periodic inspection (weekly to fortnightly) and removal of any infested produce is essential. Check for droppings and footprints of birds and rodents. Look for flying moths at dusk. Brush stacks of bags with a stick or broom to disturb and discover resting moths. Lift bags in order to detect moth cocoons along the line where bags touch each other.

When looking for beetles, pay particular attention to cracks, bag seams and ears where they often hide. Empty individual bags in a thin layer onto a sheet and examine the contents for beetles and larvae. This should be done in the shade so that the insects do not flee immediately.

Insects can also be sieved out using a box sieve with a mesh of 1mm to 2mm. Identify the insect found in order to perform the correct treatment. These measures should prevent the breeding of carry-over insects from former crops. The surroundings should also be cleared to discourage easy re-infestation by insects and rodents.

Infection with fungi can be detected by the mouldy smell, which is noticeable even before any visual changes to the product can be seen. Pay attention to water marks on bags, which can still be noticed after the bags have dried.

9. Store fumigation

Farmers in the Philippines as well as in Benin light fires, in which powdered chilli pepper is burnt underneath grain stores once a month to keep away storage pests. One disadvantage is that the smoke is very sharp and uncomfortable for human eyes and respiratory system.

10. Store disinfection

After the store has been cleaned completely and all old deposits of dust (possibly containing insect eggs) has been removed, it is good practice to dust the whole store with diatomaceous earth, lime or ashes, to prevent potential problems. Where larger grain borer has attacked the wood in the construction, the wood should be treated with any of the approved wood preservatives or thoroughly sprayed with a kerosene oil mixture to get rid of any surviving grain borers.

Additives are useful to protect stored produce from pest attack

The use of mineral substances such as fine sand, clay dust, lime and wood ash cause invisible injuries to the stored food pest, leading to it becoming dehydrated. They also fill the spaces between the grains, making it difficult for the pest to move and breathe. When using mineral substances the amounts required are around 50g to 100g/kg of stored product, except for sand, of which larger amounts are required.

The addition of ashes, fine sand, lime, diatomaceous earth and mineral or vegetable oils is particularly useful for protecting small farm seed storage, or for storing small amounts for replanting. However, this is not always practical for large quantities of seed in terms of the labour required. For larger amounts of grains and seeds it is often more practical to simply mix the seed with any strong smelling plant material available to repel insects. Some plants such as pyrethrum and derris can actually kill storage insects.

Wood ash

Wood ash either alone or mixed with powdered chilli pepper is an efficient method of pest control. However, ashes may have an effect on the taste of the treated product. The success of this method depends on the amount of ashes being added. Ashes at 2% to 4% by weight of grain is said to give 4 to 6 months protection if the moisture content of the grain is below 11%. Ashes from casuarinas, derris, mango and tamarind are particularly suitable. Any other ash mixed with powdered pyrethrum, Mexican marigold or syringa seeds will increase the protection against insects. Ashes do not control the larger grain borer.

Lime

Mixing seeds with 0.3% lime have given good results in weevil control.

Sand

In districts where fine sand is easily available, it can be used for the protection of stored products. It is best used with bigger seeds, where the spaces between the larger seeds are filled with sand and can easily be removed again by sieving. The more sand used the better, but at least equal amounts of sand and seed should be used.

Diatomaceous earth

Diatomite or diatomaceous earth (DE) is mined in southern Africa and can be obtained at a very reasonable price. It consists of tiny fossil diatoms, whose skeletons, made mostly of silica, form the diatomite deposits. Diatomite is a very effective and non-poisonous insect killer. As a dust it can absorb a lot of water and kills insects by drawing moisture out of them. It has been used in South Africa for many years by organic farmers in various kinds of insect control.

Farmers using ½ kg DE/bag of grain do not experience any problems with weevils.

Bt. (Bacillus thuringiensis)

Bt in powder form mixed with fine sand is effective against potato tuber moth. It is also effective against grain moths.

Vegetables oils

Oils of coconut, castor bean, cottonseed, groundnut, maize, mustard, safflower, neem and soybean affect the egg laying and egg and larval development of stored pests. The addition of vegetable oil is particularly useful in protecting legumes against pulse beetles (bruchids). Losses in pulses can be prevented with the addition of 5ml oil per kg of grain/seed. To be effective, the seed must be coated properly with oil. Sunflower oil is not very effective. The effect of oil treatment decreases with time, so seeds stored this way should be treated again at any new sign of infestation. Small seeds may lose some of their germination capacity after oil treatment. If neem seed oil or any other non-food oil is used, the bitter taste can be removed by immersing the seed in hot water for a few minutes before food preparation.

Admixture of plant parts

Traditionally, many different types of plant parts are used against store product pests.

Examples of plant materials that help protecting the stored grain/seed:

Plant names	Plant parts	Treatment
Aloe	Whole plant	Parts dried, ground and dust mixed with the grain
Chilli peppers	Ripe, dried pods with ashes, dung or fine clay	Whole pods mixed with grain or dusted as powder and mix with grain/seed.
Pyrethrum	Flower heads	Pick on hot days. Dry in the shade. Crush to powder and mix with the grain/seed.
Sunnhemp (Crotolaria)	Seeds	Mix seed between gaps in stored larger size grains.
Datura (thorn apple)	Leaves and stem (careful - seed are very posonous)	Dry and mix with produce.
Derris	All parts	Stored produce dusted or stprayed
Eucalyptus	Leaves	Layered or mixed with stored produce
Lantana sp.	Leaves	Crushed and placed among seeds
Syringa (Melia Azedarach)	Leaves, ripe seeds	Dried, powdered, mixed with stored grain using 2% if powder from seed, 4% if powder from leaves

Mexican Marigold	Whole plants	Add dried plants in layers, or mix in powdered plant or place 3-5 cm layer of crushed plants in base of grain bins
Spearmint	Whole plant	4% leaf powder will give good protection for more than 4 months
Neem	Leaves, crushed seeds and their extracts and oils	-

The dosages of plant substances required are generally around 50g per kg of stored product (Gwinner et al., 1990).

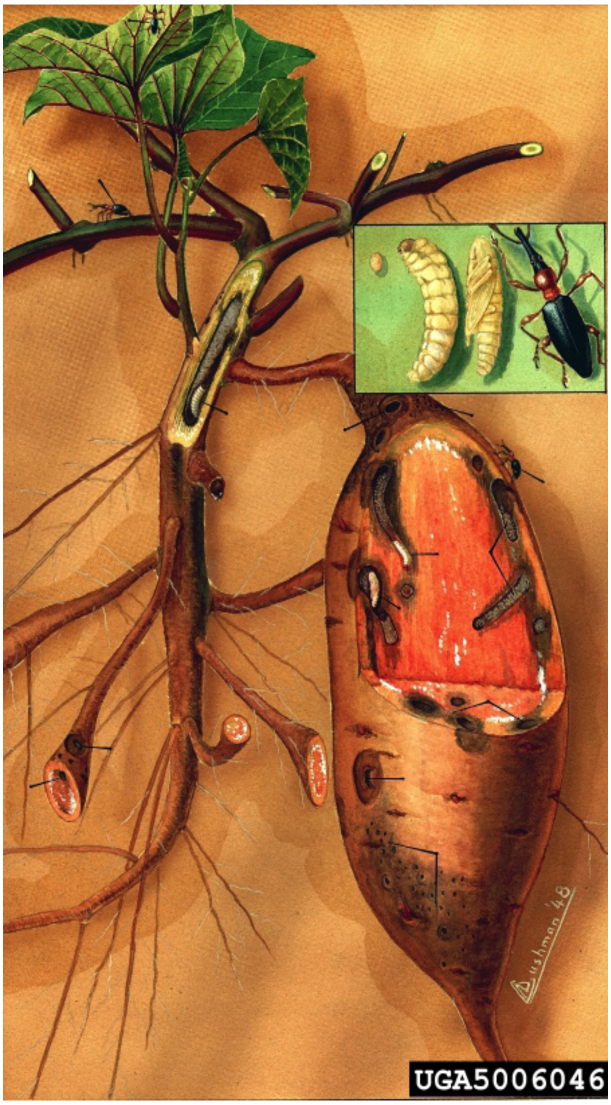
3.6.25. Sweet potato weevil

3.6.25.1. Scientific and common names

Cylas spp

3.6.25.2. What it is

The African sweet potato weevil *(Cylas puncticollis)* is one of the most important pests of sweet potato in tropical Africa, notably Uganda, Rwanda, Kenya and Cameroon. *Cylas brunneus* is present in West and Central Africa and some countries in East Africa (Rwanda, Burundi and Kenya). These two species are found together attacking sweet potatoes in East and West Africa (Hill, 1983). *Cylas formicarius* is a destructive pest of sweet potato throughout most of the tropical and subtropical regions and occurs in several African countries.



Sweetpotato weevil life cycle - Art Cushman, USDA Systematics Entomology Laboratory, Bugwood.org

The egg of *Cyclas* is oval in shape and yellowish-white in colour. It is laid singly in small cavities on the sweet potato root or at the base of the vine. The cavity is then sealed with a plug of the mother's excrement (faecal material). The egg hatches in about 3 to 7 days depending on the environmental conditions.

The larva is a legless grub, white in colour and when fully-grown, is about 8mm long. The head is comparatively large and brown or pale-yellow. The body is slightly curved. The grub is found feeding on the vine near the base of the plant and goes down to the roots to feed. Larvae develop about 11 to 33 days before pupating.

Sweet potato weevil larvae

The fully-grown grub turns into a pupa in an enlarged area of the feeding tunnel. The pupa is whitish and about 6mm long. Initially it is white, but with time it becomes greyish in colour with darker eyes and legs. The pupa is similar to the adult in appearance, although the wings, the head and the long snout are bent downwards. Adults emerge after 7 to 28 days depending on the environmental conditions.

Sweet potato weevil adult - Florida Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services, Bugwood.org

The adult insect is a weevil. Weevils are beetles with a long pointed snout. The body of the sweet potato weevil is slender resembling ants. The length of the adult is between 6mm to 8mm. They vary in colour and in size according to the species. *Cylas puncticollis* is larger and entirely black. *Cylas*

Sweet potato weevil female

brunneus is brown with blue or bluish-green elytra (hard wings) and reddish legs and is smaller than *C. puncticollis. Cylas formicarius* is as small as *C. brunneus* but has a bluish-black abdomen and a red thorax.

The weevils complete their lifecycle in the storage roots (tubers). They fly infrequently and generally for only short distances (500 to 1 000 m). The development of the weevil from egg to adult takes 32 days on average. The main host of all species of sweet potato weevil is sweet potato. Alternative hosts are morning glory, water spinach *(Ipomoea aquatica)* and other Ipomea weeds. Cylas bruneus has only been reported to attack sweet potatoes. *Cylas puncticollis* attacks coffee, maize, cowpea, sesame and *Cassia acutifolia (C. senna)* (CABI).

3.6.25.3. The damage caused

Adult weevils feed on leaves, the underground storage roots (tubers) and the vines of sweet potatoes. They prefer to feed on storage roots, but at the beginning of the growing season, when the plants have not yet produced storage roots, the adult weevils live on the stem and leaves. They lay eggs on vines and leaves and the grubs will feed in the stem or the leaf and pupate inside the vines.

As the plant gets older and starts to form storage roots, the weevils search for exposed roots. Since they cannot dig, they reach the tubers through cracks in the soil. Weevils feed on the storage roots and lay eggs just below the surface of the root. Feeding and egg-laying punctures (numerous small holes) lower the quality of the root and can reduce the market price of its crop. If roots with egg punctures are stored they will serve as source of infestation for the clean roots stored beside them. Adult feeding on the foliage is seldom of importance.

The grubs are more damaging as they feed, bore and tunnel into stems and roots. Damage to the stems may cause serious mortality to seedlings. Allard et al. (1991) reported on serious weevil attacks on sweet potato nurseries in Ethiopia. Feeding in the vines causes thickening and malformation and often cracking of the tissue. A damaged vine is discoloured, cracked, or wilted. Stem damage is believed to be the main reason for yield loss, although damage to the vascular system caused by feeding, larval tunneling and secondary rots reduce the size and number of roots.

An infested tuber is often riddled with cavities or tunnels. These wounds serve as entry point for infections, causing it to rot. Attacked tubers start rotting from the top and develop an unpleasant smell and a bitter taste, making them unfit for human consumption. Even low levels of infestation can reduce root quality and marketable yield because the plants produce a bitter toxin (terpenoid) in response to feeding attacks by weevils.

Weevil damage increases the longer the crop remains unharvested. In Kenya, where farmers practice piece meal harvesting, losses are in the order of 10%. Pest damage usually continues during storage, therefore infested tubers cannot be stored for a long time. In conjunction with other beetle pests, *C. puncticollis* can completely destroy sweet potato plantations.

Damage by weevils can be recognised by the holes in the vines or the tunnels in the tuber when pulled from the soil.

Symptoms

A symptom of infestation by sweet potato weevils is yellowing, cracking and wilting of the vines, but a heavy infestation is usually necessary before this is apparent. Damage by weevils can be recognised by the holes in the vines or the tunnels in the tuber when they are pulled from the soil. Attacked tubers become spongy, and brownish to blackish in appearance.

Affected plant stages

Flowering stage, fruiting stage, post-harvest and vegetative growing stage

Affected plant parts

Leaves, roots and stems

Symptoms by affected plant part

Leaves: external feeding
Roots: rot; internal feeding; external feeding.
Stems: external discolouration; abnormal forms; internal feeding; external feeding

Sweet potato weevil damage John Ruter, University of Georgia, Bugwood.org

Sweet potato weevil damage

3.6.25.4. Cultural practices to prevent its occurrence

Cultural practices

Monitoring

At the beginning of the growing season, when the plants have not yet produced any storage roots, the adult weevils are commonly found on the foliage, but they quickly drop to the ground if disturbed. During the day they hide under leaves or in soil cracks. Most of the larvae are found in the upper 15cm of the tubers and basal 10cm of the vine. Select storage roots that appear soft, smelling, or have external scarring or small, darkened holes. Cut these open and look for tunneling and larvae. Pheromone traps are useful in monitoring weevil populations, but this technology is expensive and not widely available.

Among various control measures attempted, modification of cultural practices has the greatest potential in combating the sweet potato weevil at low cost.

Crop rotation

Avoid planting sweet potatoes in the same area for two to three consecutive seasons. It has been suggested that, if possible, sweet potatoes should be grown in a field only once every five years. Rice and sorghum are often used in rotation with sweet potatoes. This rotation will help break up the cycle of the weevil and will help to control sweet potato weevil infestation, particularly if integrated with other management approaches, such as the ones described below.

Intercropping

Experimental studies in Taiwan showed that intercropping with chickpea, coriander, pumpkin, radish, fennel, black gram and yard long bean reduced weevil infestations considerably. However, intercropping with black gram, fennel, pumpkin and yard long bean also reduced sweet potato yields. The best results were obtained with coriander. Similarly, reduced weevil damage was observed when sweet potato was intercropped with proso millet and sesame, but sweet potato yield was also considerably reduced. Sweet potato has been found to inhibit germination of proso millet (Peterson et al., 1999).

Planting time

Plant early or plant early maturing varieties. This will allow harvesting before the end of the growing season, minimising the risk of drought and consequently the damaging effect of weevils, which enter the soil through cracks.

Use of clean cuttings

Carry-over of the weevils from an infested crop to the new planting cycle could be reduced by carefully selecting fresh cuttings for planting a new crop. Use clean, insect-free vines as planting material. Preference should be given to planting material from vine tips. Weevils tend to lay eggs in the older woodier parts of the vine, so if the tender tips are used for planting, they are less likely to be infested by weevils. Studies in Taiwan showed that cuttings (25cm to 30cm long) taken from fresh terminal growth, even from an infested crop, were rarely infested with weevils, whereas older portions of the stem were (AVRDC).

Keep distance to infested fields
Planting away from weevil-infested fields and/or using barrier crops such as cassava, maize, bananas or sorghum planted around the perimeters in strips of at least 3 to 5m in width, between fields have been observed to restrict movement of weevils between fields (CIP, VITAA).

Avoid soil cracking
Avoid or minimise cracks in the soil. Soil cracks are the major reason why weevil can access roots. This can be done by:

- Planting cuttings deep in the soil and using deep-rooted cultivars to reduce weevil damage. The growth of roots, especially in cultivars that set roots near the soil surface can produce cracks and increase exposure of roots to the weevil
- Ridging: it prevents the soil from cracking by hilling the area around the plant. Re-hill mounds about 30 days after planting to close soil cracks. Close ridges after piece meal harvests to cover exposed tubers. This should be implemented before the adult weevil reaches the roots
- Mulching: mulches conserve soil moisture and minimise soil cracking. The physical cover made by mulching materials further reduces access to the roots even if the soil cracks. The soil surface should be covered soon after planting and the cover should be maintained until harvest
- Routine irrigation: it is important to provide sufficient water to prevent soil cracking. This is a practical method for farmers with a reliable water supply

Sanitation
Remove and destroy (through burying, burning or feeding to livestock) any crop residues left in the field after harvest. Infested roots must be completely buried (over 15cm deep); avoid cracks, which allow emerging weevils to reach the soil surface. If vines are left in the field to improve soil fertility, care should be taken to ensure they are dead and not able to sprout. Care should be taken to remove and destroy any infested roots when doing piecemeal harvest.

Field sanitation is important because weevils survive in roots and stems and infest succeeding or neighbouring sweet potato plantings. However, to effectively reduce weevil infestation it should be practised in a large area or community. Clean cultivation is particularly important, where rotation is not possible, for example in areas where sweet potato is a staple food and is planted throughout the year.

Flooding of fields
Flooding infested fields for at least 48 hours after completing a harvest drowns weevils and induces rotting of the leftover plant materials, reducing weevil densities from one planting to the next. This is an option in areas where rotation is not possible and water is plentiful.

Flooding of fields between two consecutive sweet potato crops may reduce the immediate source of weevils from the field.

Early harvesting
Harvest the crop as soon as it has developed roots of acceptable size.

Control of alternative hosts
Alternative hosts of the sweet potato weevil (e.g. morning glory, water spinach, wild Ipomoea etc.) can shelter weevils between planting seasons and serve as a source of weevil infestation when a new crop of sweet potato is planted. Therefore, removal of these host plants growing in the vicinity of sweet potato plantings is recommended as a control measure. However, indiscriminate elimination of these plants is not recommended since it may lead to undesirable ecological

effects. To minimise this, all Ipomoea could be eliminated for one cropping season and allowed to grow in the subsequent seasons, once the area is free of the weevils.

3.6.25.5. Remedies

Biological pest control

Natural enemies

Predatory ants, earwigs, spiders and ground beetles are important predators of the sweet potato weevil. Among those, ants seem to be most important. In Cuba, two species of predatory ants, *Pheidole megacephala* and *Tetramorium guineense*, which are common inhabitants of banana plantations, are used for control of sweet potato weevils. These ants are encouraged in reservoir areas, such as patches of forest, where they are naturally abundant. Ants nests are moved by a simple method using rolled banana leaves as 'temporary nests' to transport the ants from their natural reservoir to sweet potato fields. Alternatively, banana stems baited with honey are placed in the natural reservoir area and, when covered by ants, are transported to the sweet potato fields. The ants then prey upon sweet potato weevils and other insects. Setting up colonies in the field 30 days after planting with 60 to 110 nests/ha can keep weevil infestation at low levels (3 to 5%) (FFTC; Sheehy Skeffington, 2006).

Disease-causing microorganisms, especially the fungus *Beauveria bassiana*, have been observed to cause high mortality of sweet potato weevils in the field under conditions of high humidity and high insect density. It can be used for treating the planting material and the soil to reduce soil infestation.

Traps

Pheromone traps are widely used for monitoring the sweet potato weevils. However, these traps are expensive and not widely available. In 1995, a collaborative project of the National Agricultural Research Institutes, Natural Resources Institute (NRI) and the International Potato Centre (CIP) began developing pheromones for monitoring and controlling the African sweet potato weevils in East Africa. Pheromone compounds that proved effective in catching male weevils under field conditions in Uganda were identified and several traps were tested. A 5l plastic jerry can with rectangular openings of 11 × 5cm and 6 × 5cm filled with 0.5l soapy water (1g Omo/1l water), with 0.1mg lures to be replaced every eight weeks is presently the most effective and robust trapping system. Experiments on the use of these traps for mass trapping of male weevils are on-going (CIP; Smit *et al*., 1997).

Farmer's experience

Farmers in Kilifi Kenya have found their own unique solution to the control of sweet potato weevil. They make use of the abundantly available insect repellant *Lantana camara* bushes, in their area at planting time. When preparing planting ridges for sweet potatoes, fairly large amounts of lantana leaves/branches are incorporated into the ridges. This serves two purposes:

1) it adds organic matter and is fertiliser to the soil and

2) it keeps the sweet potato weevils away.

This simple planting method makes the Kilifi farmers able to produce larger and better quality sweet potatoes than most of their neighbouring communities.

3.6.26. Termites

3.6.26.1. Scientific and common names

Ancistrotermes spp., Amitermes spp., Coptotermes spp., Macrotermes spp., Microtermes spp., Odontotermes spp., Pseudacanthotermes spp
White ants; harvester termite *(Hodotermes mossambicus)*; bark-eating termites (Macrotermes spp., Odontotermes spp.)

3.6.26.2. What it is

Termites are probably present in most, if not all, African countries.

Termites are social insects, living in large colonies consisting of many workers, soldiers and reproductive forms. They sometimes live in elaborate nests; some build nests on moist dead tree stumps, while others build subterranean nests, which in many cases have mounds that may reach 2m in height. They forage away from the nest, protected by underground tunnels or soil-covered tunnels.

Termite mound

Termites feed on dead plant material, such as wood, leaf litter, roots, dead herbs and grasses, dung and humus. Some termites are able to digest cellulose (wood) with the assistance of symbiotic (mutually beneficial) bacteria present in the gut of the termites. Other termites use the cellulose to cultivate fungi that are then eaten.

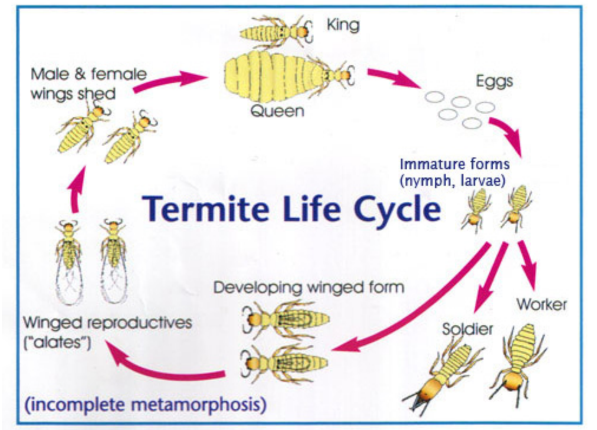
Termites & fungi

Eggs hatch into tiny larvae, which are incapable of feeding on their own and are raised by specialised workers in the colony. Larvae are capable of developing into any caste (workers, soldiers or reproductive forms), depending on time of year, diet etc.

Workers are whitish, wingless and usually blind. They have pale yellow round heads and comprise the bulk of the population. Workers feed all the dependent castes. They also dig tunnels, locate food and water and build and repair the nest.

The soldiers are whitish, wingless and blind; they are larger than the workers and have large, brownish heads and strong jaws. With their specialised defensive weaponry, the role of the soldiers is to protect the colony against numerous predators such as ants and centipedes.

The reproductive termites are winged and are known as alates. Numerous winged males and females, generally dark in colour and with well-developed eyes, are produced for



Termite life-cycle

swarming. Swarming is often at dusk after the onset of heavy rains. After flying, they shed their wings, mate and burrow into holes in the soil and cracks in wood to found a new colony. The queen termite typically develops an enormously distended abdomen. At her peak, a queen will be laying an egg every 3 seconds or 30 000 a day in some species; and she will lay tens of millions of eggs during her life.

3.6.26.3. The damage caused

Termites primarily feed on wood, but some species collect green grasses and seeds and store these in their granaries inside their nest as food reserves. They are sporadic pests and are important in a wide range of crops.

Some termites eat into the tap roots of young plants (e.g. cotton and groundnut) immediately below the soil surface, destroying the central root portions and fill the resulting cavities with soil. Damaged plants wilt and may die within a few days particularly under drought conditions. Some termites also attack the roots of maize and sorghum and the damaged plants topple. Termites may also travel up through the roots into the trunk and branches. They eventually disrupt the movement of nutrients and water through the vascular system, resulting in the death of the plant.

Bark-eating termites attack a wide range of crops and occasionally, are locally important pests. They cover the tree trunks or plant stems with tunnels built of soil, plant fragments and saliva and gnaw away at the bark underneath these tunnels. Some damage is done to the roots and the underground stem of the plant. The collected plant material is taken back to the nests for construction of fungal gardens.

Termite earth tunnels on a mango tree

Tunneling damage may kill seedlings or ring-bark trees when large cavities are eaten out of the trees. However, they do not cause damage when feeding on the dead bark of established trees. Sometimes root damage may be serious. Some termites gain access through the dead ends of pruned branch stumps, from which they may invade the living tissues.

The sugarcane termite *(Pseudacanthotermes militaris)* causes poor germination of sugarcane setts and when it attacks mature cane, the cane is encrusted with earthen tunnels and stalks are often felled when nearing maturity. This termite is a major pest of sugarcane. Other species of termites can also cause considerable damage to sugarcane; under severe attack no shoots can be formed and large gaps are left in the field.

Harvester termites cut and gather pieces of grass and wood, leaf and herbaceous twigs and carry them to the mounds. They have small earth mounds (about 10cm) scattered through areas with short grasses. They are major pests of grasslands and occasional pests of cotton, wheat and groundnuts.

Harvester termites taking plant material into the nest

Several species of dry wood and subterranean termites are storage pests and can become a problem in farmers' granaries or in village stores. Most of the damage occurs in wooden storage structures, but some subterranean termites also feed directly on the stored grain. Direct grain losses due to termite feeding are generally low, but contamination with moulds, as a consequence of their attack, is frequent.

Symptoms

The first signs of termite attack on roots seedlings or on older plants is wilting. Eventually some plants die or fall over. Pulling out the affected plants and examining the roots and lower stem for live termites and tunneling will confirm the presence of termites. Plant roots and stems may be completely hollowed out and soil-filled.

Often plants in the field are covered with soil runways or soil sheeting, under which termites may be found. It is important to examine plants in the early morning or late evening, as termites may have moved deeper into the soil during the day when temperatures are high.

Termite attack on trees and bushes often begins in an area of dead wood produced by pruning or other damage. Small cracks or tunnels made by other insects such as wood-boring beetles may allow winged termites (indicating their reproductive stage) to enter. Termites may also travel up through the roots into the trunk and branches. They eventually disrupt the movement of nutrients and water through the vascular system, resulting in death of the plant.

Galleries in the wooden parts of the construction reveal the presence of dry wood termites in granaries. As termites avoid the surfaces of attacked wood, their presence may only be detected after substantial damage has occurred. Subterranean termites construct visible galleries that are used as runways.

Entrance to termite's nest

Affected plant stages

Flowering stage, fruiting stage, post-harvest, seedling stage and vegetative growing stage

Affected plant parts

Leaves, roots, stems and whole plant

3.6.26.4. Cultural practices to prevent its occurrence

Cultural practices

The following find is a list of cultural practices for the management and prevention of termite attack:

Promote conditions for healthy plant growth to prevent termite damage. Termites often attack sickly or water stressed plants more than healthy plants.

Avoid unnecessary injury to the plants as this may facilitate entry of termites.

Plough fields to destroy termites' nests, runways and tunnels and to expose them to predators, such as ants, birds, chickens etc.

Practise crop rotation to reduce the build-up of termites. Planting the same crop every cropping season makes it susceptible to termite attack.

Grow crops in mixed cropping systems to reduce termite damage. Know and make a list of the annual crops that are attacked by termites.

Remove plant residues and other debris especially moist and decaying wood. However, take into account that termites may attack plants if there is no other food available, for instance if there is no other source of organic matter such as soil humus and mulch; therefore ensure that there is plenty of soil humus; avoid bare, dry disturbed, organic-deficient, residue-free soil.

Inspect plants, especially the pruned fruit trees, for termite attack. Do this either early in the morning or late in the afternoon.

Remove affected plants or part plants to kill the termites; they are normally found inside the hollowed parts.

Harvest at the right time, as termites often attack maize, sorghum and millet left in the field after maturity. The attacked stalks may fall down and the termites may attack the cobs and panicles.

Where there is risk of termite infestation, avoid leaving the crop in the field after harvest, on stacks or windrows.

3.6.26.5. Remedies

Biological pest control

Natural enemies

Termites are attacked by a wide range of natural enemies, including man. In Africa masses of reproductive forms are caught in simple traps and eaten raw or roasted in oil. Natural predators include ants, dragon flies, ground beetles, some spiders, bats, and many species of birds, frogs and some large mammals (aardvarks, pangolins and monkeys).

Despite the large number of predators, most termites are able to maintain high populations by means of mass production of reproductive forms.

Biological control measures against termites are generally difficult because of their social nature and secure enclosed environments that protect them against most natural enemies. Preparations based on insect-attacking nematodes and the fungi *Beauveria bassiana* and two species of *Metarhizium* are effective when applied into the mounds. Fungi spores can act as repellents.

Bio-pesticides and physical methods

Neem

Neem products reportedly have a repellent effect on termites. *Odontotermes spp.* and *Microtermes obesi* were repelled from scarifying groundnuts pods lying in heaps on the ground, by a layer of neem cake between the surface of the soil and the pods (Gold et al, 1989). Neem oil and neem leaves reduced the weight loss of wood pieces exposed to termites (Sharma et al, 1990). Neem seed extracts have been used against Microtermes termites on trees and Odontotermes termites on field crops with good results (Schmutterer, 2002).

Ash

Heaping wood ash around the base of tree trunks or mixing it into seedling bedding soil is reported to reduce termite attack. Wood ash should be replaced regularly.

Compost tea & EM/IM preparation

Good success has been achieved in pouring compost tea, EM or IM preparations down the tunnels of fungi growing termites. The beneficial microbes in the compost/EM parasitise the feeding fungus beds and out-competes them for the food source. This eliminates the food source of the termites and lead to their demise.

Physical measures

- Burn plant residues on top of termites' mound to suffocate them. However, this does not give long lasting results, as it does not penetrate deep enough to kill the queen
- Locate their soil runways/tunnels and destroy the worker termites either by hand tilling or by flooding. This is not a long lasting solution since the termites would eventually re-infest the plants
- Destroy termite mounds manually. However, this method is labour intensive since the building material of the mounds is very hard and some mounds are large. To be effective, the queen has to be found and destroyed; the queen may be hidden deep inside and is not easily found. After killing the queen, pour boiling water or burn dried grass straws (any plant debris) to kill the rest

Protection of traditional granaries

- Clear the building site of the granary from all organic material that might attract termites, such as wood and straw. Dig out roots of chopped trees and shrubs that have been left in the ground close to the storage structure. Keep the ground around the building free from any plant growth
- Avoid construction sites that are infested with termites or are close to such areas
- Use termite resistant timbers such as teak as poles for granaries. If termite resistant wood is not available, protect the poles by charring the outer layer of wood or by coating the poles with engine oil
- Pour used engine oil, wood ash or pounded neem leaves or seeds into the pole holes in order to repel termites
- Use concrete or stone platforms resting on poles made out of the same materials as the basement for grain stores
- In areas where termites occur regularly, avoid placing granaries directly on the ground and using mixtures of clay with straw, because termites are encouraged to tunnel thought the walls. Use pure adobe walls instead
- Underground pits are easily invaded by termites; to avoid this, line with the pits with clay or soil from termite mounds, which is then fired to harden
- Apply a layer of ash to the base of the granary, or plant materials with insecticidal or repellent properties to the grain

3.4 Examples of pest management plans

3.4.1 An example of a pest plan for controlling fruit flies

The following is an example of a pest plan to control fruits flies so that undamaged, pest free fruit can be sent to markets. Fruit flies are one of the major trade quarantine issues because of the extensive damage they can cause to a large range of fruits.

They are mostly controlled by the spraying and the post-harvest dipping into solutions of highly toxic organophosphate chemicals. These are in the process of being banned by most markets because of a range of serious health effects they can cause to humans, especially children who consume low levels of the toxic residues in the fruits.

The alternative to chemical treatments being proposed by several governments is to irradiate the fruit with ionising radiation. The organic movement does not permit ionising radiation as a food treatment as the science shows that the radiation creates a range of new compounds called unique radiolytic compounds. These have been shown to damage the DNA and other parts of the body in test animals and are precursors for cancerous changes in cells.

It is important that organic producers have alternatives to toxic chemicals and ionising radiation to produce fruit that are not damaged or infected by fruit fly larvae.

Management plan for controlling fruit flies

Good organic pest and disease management plans always use a range of multifunctional strategies to deal with the pest and disease, rather than just relying on one type of treatment whether chemical or by irradiation for achieving effective control.

The plan below utilises a number of strategies to control fruit flies:

1. Keeping fruit fly numbers as low as possible by not feeding them

Fruit flies live on enterobacteria that feed on the excess nitrates that are excreted on the undersides of leaves. By avoiding soluble nitrate fertilisers and only using nitrogen in organic forms, organic farmers can ensure that very little nitrate is excreted by the leaves on the trees to feed the enterobacteria and fruit flies.

2. Encourage beneficial species

The use of insectary systems and not destroying beneficial species with toxic chemicals means that there are a lot of predator species in the fruit trees like spiders, ants and assassin bugs that eat fruit flies.

3. Use protein hydrolysate baits to kill the female fruit flies

Adult fruit flies do not eat fruit. They eat enterobacteria. The females lay their eggs into the fruit and when the larvae hatch they start to eat the fruits. One of the most effective strategies is to use protein hydrolysate baits to attract and drown the females before they lay eggs in the fruit and catch the males before they mate.

These are easy to build by making a hole about 25mm in diameter near the top of a used plastic drinks bottle. The bottom third of the bottle is filled with a mixture of hydrolysed protein and water. This is usually a common yeast extract that can be bought in most supermarkets.

The lid is screwed back on and the bottles are hung in trees. Enterobacteria will quickly grow in the liquid. The fruit flies smell them, enter the bottle and drown in the non-toxic liquid. Top up the baits every week with fresh mixture of the protein hydrolysate.

4. Male eradication

Commercial parahormone lures are available for the males. The aim of these lures is to trap them before they can mate with the females to break the cycles. These lures tend to use organophosphate pesticides that are prohibited in organic agriculture. Some certifiers will permit their use if the lures are in containers and disposed of outside of the farm so that it has no pesticide residues.

Farmers can make their own lures by building the same soft drink trap as described in section 3 above, however filling them with water and small amounts of essential oils that contain Eugenol, such as clove oil, nutmeg oil or citronella oil. Eugenol is a para-hormone that is used by many species of young fruit flies to produce the hormones they need to become sexually mature. Organic producers have found from experience that using a mixture of the oils is better than using just one. This is because there are several variations of these Eugenol type compounds and some are more attractive to different fruit fly species than others. Having a mixture means that there is a better spectrum of these compounds to attract the desired species of fruit flies.

5. Constant harvesting to remove ripe fruit from the trees

Fruit flies prefer to sting ripe fruit. It is critical to develop regular harvest cycles that remove all of the ripe fruit and only keep the fruit on the trees or vines at the hard green stage.This significantly reduces the breeding cycle and helps to ensure that harvested fruit is not stung.

6. Remove and destroy all fallen fruit from under the trees

The larvae live in the over-ripe fruit and pupate in the ground. Removing and destroying the fallen fruit stops larvae from developing into the next generation of adults. The use of chickens, geese and other fowls to roam the orchard and to eat all fallen and mature fruit is a good way to prevent the breeding cycle. Fowls such as chickens that scratch around the ground will find many fruit fly larvae or pupae and eat them.

7. A strict post-harvest inspection system

Develop a strict post-harvest inspection system to remove any potentially infected or damaged fruits. Fruit flies prefer to sting fruit with broken or damaged skin. These fruits should be destroyed and not sent to market. Removing these fruits from a consignment sent to market improves the visual and eating quality of the fruit. This should return a higher price to the grower because of the higher quality.

8. Packaging that will prevent contamination

It is important the harvested fruit is packed in containers that do not have any holes that fruit flies can pass through to sting the fruit. Harvested fruit is more attractive to fruit flies because it is starting to ripen. An example of an organic pest control plan for tropical fruits: A generic plan that can be used as a template as the basis of a pest and disease control plan for fruit orchards.

It is the nature of farming that each region will have different issues that they have to deal with, even when they are growing the same crop. This is why good organic farmers rarely use the simple recipe systems that tend to be used by conventional farmers.

Organic farming is about developing management systems that are specific to each farm and its unique requirements. These systems will not just have one strategy. They will have several strategies that are integrated into a whole-system approach.

Step 1:
Identify common pests and diseases

The first step in the plan is to identify the pests and diseases. Write them down in a list.

Step 2:
Identify the multiple control mechanisms and strategies

This step involves listing the control mechanisms and strategies that the farmer knows that will control or partially control the pest.

An example of this type of list is below:

Pest: Lepidoptera (caterpillars)

Controls:

- *Bacillus thuringiensis var.kurstakis*
- Nuclear Polyhedrosis Virus
- Fungal diseases such as *Nomuraearileyi* and *Beauveria bassiana*
- Potassium soap
- Emulsified vegetable oils
- Natural pyrethrums
- Assassin bugs, *Trichogramma* and other miniature wasps
- Lace wings, hover flies, green ants
- Insect eating birds

Pest: Coleoptera (Beetles –Monolepta, Rhyparida and other spp)

Controls:

- Bacillus thuringiensis var.enebrionis
- Metarhizium sp.
- Potassium soap
- Emulsified vegetable oil
- Repellent sprays such as chilli, pine oil, eucalyptus oil
- Natural pyrethrums
- Assassin bugs, spiders, green ant
- Insect eating birds

Pest: Mites

Controls:

- Predatory mites
- Spiders
- Wettable sulphur
- Emulsified vegetable oils
- Potassium soap

Pest: Mealybugs and Scales

Controls:

- Predatory mites, ladybirds, assassin bugs, lacewings, spiders
- Emulsified vegetable oils
- Potassium soap

Pest: Nut borers

Controls:

- Ladybirds, assassin bugs, lacewings
- Spiders, hover flies, green ants
- Trichogramma and other miniature wasps
- *Bacillus thuringiensis var. kurstakis*
- Nuclear Polyhedrosis Virus
- Fungal diseases such as *Nomuraea rileyi* and *Beauveria bassiana*
- Potassium soap
- Emulsified vegetable oils
- Natural pyrethrums
- Insect eating birds

Pest: Shield bugs and fruit spotting bugs

Controls:

- Assassin bugs
- Big eye bugs
- Spiders
- Insect eating birds
- Natural pyrethrum
- Emulsified oils
- Repellent sprays such as chilli, pine oil, eucalyptus oil

Pest: Fruit sucking and fruit piercing moths
Controls:
- Micro bats
- Improved netting systems

Pest: Vertebrate pests
Controls:
- Improved netting systems
- Improved scaring systems

Disease: Fungal problems
Controls:
- Wettable sulphur
- Emulsified vegetable oils
- Potassium soap
- Copper sulphate
- Micronised copper
- Tea tree oil
- Sodium bicarbonate
- Potassium permanganate
- Lactic acid bacteria
- *Trichoderma sp.*

Step 3:
Divide these mechanisms and strategies into short term (immediate) and long term mechanisms

The purpose is to have strategies to deal with immediate pest and disease problems when they arise and also strategies that will prevent the problems from occurring.

The long term prevention must always be the most important aim with the short term seen as the back-up for the times when the pests or diseases become acute problems.

Short term pest control

Example:

Spray wettable sulphur on the emerging crop flowers to protect them from mite damage. At this stage use Bt to protect the flowers from caterpillars and a combination of repellent sprays to prevent beetle damage.

Hot Spots of damaging beetles can be controlled with a mixture of natural pyrethrums, natural soap and emulsified vegetable oils.

These short term pest control treatments are applied on a needs basis, based on daily monitoring of the flowers, not on a calendar based program. The products, rates, dates and areas treated should be recorded in the farm's spray and inputs diary.

Long term pest & disease controls

• Soil health

Use soil testing to understand the levels of nutrients and organic matter on the farm. This is the critical first step in developing a resilient, high yielding system.

Develop a plan with timelines on the stages needed to get the soil up to the required level.

• Bio-controls

Most orchard pests are to be controlled through a number of bio control strategies. The most important of these are to develop insectaries within and around the orchard to attract the beneficial species that control the pests and diseases.

Develop a time table to introduce host plants for beneficials either as ground covers throughout the orchard or as dedicated nature strips in the marginal areas of the farm. Never clear all the weeds in the orchard. It is important to leave pockets as refuges for beneficial insects and other organisms. These refuges are cut down in a later slashing cycle to stop the weeds from getting out of control, however new areas are then left as refuges. By doing this the weeds are stopped from competing with the crops as well as allowing them to have a range of useful functions, such as beneficial habitat, mulch, nitrogen fixation and soil stabilisation. Research has shown that these insectaries breed thousands of beneficial organisms.

Encourage small flowering plants to grow throughout the orchard, as these are essential to the adult stage of beneficial predators such as lacewings and *Trichogramma* wasps.

Allow native vegetation to regenerate in marginal areas on the farm and watercourses by planting a range of species to provide habitat for the bird species that spend many hours every day of the week removing pest species from fruit trees. These areas also host a variety of beneficial insects, mites, amphibian, reptile and mammal species that help control the pests in the orchard.

3.5 Common control methods for pests & diseases

3.5.1 Hot Water Seed treatment:

Hot-water treatment of seeds is used against the following diseases: Anthracnose, bacterial blight, bacterial leaf streak, bacterial spot, black rot, black leg, black scurf, black spot, common blight, powdery scab, ring spot, early blight, septoria spot, and Phytophtora (pineapple).

Hot-water treatment of seeds can be used for the following crops: spinach, brussels sprouts, cabbage, pepper, tomato, eggplant, broccoli, cauliflower, carrot, collard, kale, kohlrabi, turnip, mustard, cress, radish, lettuce, celery, celeriac, banana, mango, pineapple and potato.

Hot-water treatment can be used against the following pests: fruit flies (on mango fruits), banana weevil (on banana suckers), mealybugs (cassava and pineapple), nematodes (banana suckers and pineapples).

Hot water treatment of own seed to prevent seed borne diseases such as black rot, black leg, black spot and ring spot of crucifers is recommended. This treatment helps reduce the seed-borne pathogens such as *Alternaria spp., Colletotrichum spp., Phoma spp., Septoria spp.* and bacterial pathogens *(Pseudomonas spp.* and *Xanthomonas spp)*. However, specified temperature and time intervals must be strictly followed in order to maintain seed viability. Use a good thermometer. To make sure that the seed is not damaged, it is advisable to test the germination of 100 heat-treated and 100 untreated seeds.

For potato tubers heat treatment of 10min in water at 55°C was used. The same treatment of naturally or artificially contaminated seed tubers gives complete absence of blackleg infection in the field and decreases the amounts of powdery scab *(Spongospora subterranea)* and black scurf *(Rhizoctonia solani)* on progeny tubers.

Procedure:

1. In a large pot, heat plenty of water to the required temperature
2. Place seeds in a cotton bag and submerge it in water. Strictly follow the recommended temperature and the time required. It is important that the water is maintained at a uniform temperature throughout the container. Constantly stir the water while soaking the bag. Suspend the bag and do not let it touch the bottom of the pot
3. Remove the bag and cool it in clean, cold water to stop the heating
4. Spread the seeds on a clean dry paper to cool and dry
5. It is preferable to not store treated seeds. Sow them immediately on well-prepared seedbeds

Storing seeds:

If treated seeds cannot be sown immediately, a good way to store the seeds is as follows:

1. Dry the seeds in the indirect sun until they are completely dry
2. Take a clean jar, pot or bottle of clear non-coloured glass and place a clean piece of cloth with warm ashes in the bottom. You should be able to touch the ashes without burning yourself. Close the container tightly and let the ashes cool. By adding ashes, any water that gets in the container will be absorbed by the ashes and will prevent the seeds from moulding and rotting
3. After an hour or so, the ashes should be cool and you can then place the seeds, loose or wrapped in a transparent plastic bag, in the container. Close the container with a piece of plastic (or a bottle with a cork). Spread about 2mm layer of grease or vaseline over the plastic or cork so that the edges are covered to prevent moisture getting into the container
4. Store the container in a cool, dry place
5. Check regularly to see if mould has formed on the seeds. If the seeds were properly dried, the chance that mould will develop is very small. However, should you see mould, dry the seed again.

Heat treatment recommendations:

- Potato tuber: 55°C for 10 minutes
- Spinach, brussel sprouts, cabbage, pepper, tomato, eggplant: 50°C: 30 minutes
- Broccoli, cauliflower, carrot, collard, kale, kohlrabi, turnip: 50°C: 20 minutes
- Mustard, cress, radish: 50°C: 15 minutes
- Lettuce, celery, celeriac: 47°C: 30 minutes (Nega et al. 2003)

Hot-water treatment for mango fruit

Hot water treatment (HWT) is also recommended for mango fruits as an effective post-harvest treatment to minimise fruit fly damage and anthracnose.

For large commercial enterprises it is possible to immerse mango fruits in a water bath at a constant temperature of 48°C for 45 to 60 minutes. According to Joshi et al. (1995) this gives 100% control of fruit fly eggs. Temperature control is very important as fruit can be damaged by high temperatures.

For smaller operations, immersing mango fruits in water bath of 50°C for 5 minutes is recommended.

Caution:
Do not use this method without a good thermometer to measure the temperature, as fruits can be damaged by temperatures that are too hot.

Hot-water treatment for banana suckers

Hot-water treatment of suckers helps against banana weevil. Recommendations suggest immersing clean trimmed suckers in a bath with hot water at 52° to 55°C for 15 to 27 minutes before planting. There have been reports of hot water treatment killing remaining eggs and a high percentage of grubs. For example, Gettman et al. (1992) reported over 99% mortality of weevil eggs and grubs when suckers of dessert bananas were placed in a water bath of 43°C for three hours. However, other sources indicate that hot baths are very effective in eliminating nematodes, but kill only a third of the weevil grubs. Thus, clean planting material is likely to provide protection against weevil for several crop cycles (Gold and Messiaen, 2000).

Hot-water treatment for pineapple plantlets for transplanting

Hot water treatment (50°C for 30 minutes to 2 hours) of planting material is efficient and can control both mealybugs, *Phytophthora* and nematodeson pineapple plantlets. After this treatment, it is important to drip dry the planting material to avoid fungus attack and deterioration.

How can the temperature be controlled?

A simple method for farmers to control temperature has been developed in Kenya. It consists of a pith block (of about 3cm x 3cm) or a small piece of wood tied to an iron plate (3cm x 3cm and weighing about 10g) covered with a thin film of candle wax. This device is allowed to sink in a half-empty oil drum with water, in which the banana material to be treated is placed. Wood is burnt underneath the drum, when the temperature rises to 55°C, the wax melts releasing the pith or piece of wood, which then floats to the surface. At this moment the firewood is removed. (Prasad and Seshu Reddy, 1994).

Some Pesticides Permitted in Organic farming and gardening

If we think organic production means vegetables and fruits free of any chemical pesticides, we do not have the story quite right.

Organic producers can use certain pesticides – chemicals that are derived from botanical and mineral-bearing sources. These chemicals may be highly toxic, but they break down more rapidly than common chemicals, such as the Sevins, Malathions and 2,4,Ds.

The use of botanical and mineral-bearing pesticides, even though some are toxic, also can be incorporated into an Integrated Pest Management (IPM) approach to growing crops. IPM relies on a variety of pest control means rather than on one product or method. The pesticides discussed below are appropriate to include in IPM programmes.

Just as the more common chemicals are given toxicity ratings – CAUTION, WARNING or DANGER -- so are chemicals from botanical and mineral-bearing sources. "CAUTION" means low toxicity; "WARNING" means moderately toxic and "DANGER" means highly toxic. The toxicity rating for each pesticide is provided in the paragraphs below.

Consult your organic standard and/or your local certifying agency for detailed information and for advice on new 'organic' products coming onto the market all the time.

3.5.2 Copper

General information

There are many copper compounds used as fungicides. Bordeaux mixture which is a combination of copper sulphate and hydrated lime (calcium hydroxide) is recommended. Other compounds include copper oxychloride and copper hydroxide. The latter two are now commonly used and are commercially available.

Copper fungicides were formerly accepted in organic farming and can still be accepted with permission from the certifying authority, provided that the number of applications is strictly followed and a proper soil amendment is observed to prevent copper accumulation in the soil. According to the NOA standards, copper is "restricted" and can be only used where the need is recognised by the Soil Association Ltd (UK). Other organic certifying agents have differing rules.

In wet weather, fungicide sprays should be applied as soon as the disease is observed or as soon as local experience suggests that weather conditions are favourable for disease development.

Crop scouting should be used as a guide in making a decision on whether to apply a fungicide. And when applying fungicides, safety procedures in application must be complied with, particularly, in use of protective clothing. Observe the correct dosage and prescribed pre-harvest intervals.

Bordeaux mixture is primarily a fungicide that controls bacterial leaf spots, blights, anthracnoses, downy mildews and cankers.

It also repels many insects. The compound is labeled for use on many vegetables, tree fruits and nut crops.

Bordeaux mixture, as with sulphur and lime sulphur, can be phytotoxic to plants. If applied in cool, wet weather, it may burn leaves or cause russeting of fruit.

Bordeaux mix spray

Materials needed to make a 4 litre mixture:

- 3 ½ tbsp of copper sulphate
- 10 tbsp of hydrated lime
- 4 litres of water
- Wooden stick
- Plastic bucket

How to prepare:

1. Add copper sulphate and hydrated lime in water. Make sure to use a plastic container
2. Stir well using a wooden sick or ladle
3. Protect yourself from direct contact with the solution

How to use:

1. Spray plants thoroughly, preferably early in the morning, on a dry and sunny day. In this way, the plants have the time to dry and the solution cannot penetrate into the leaves' tissues
2. Constantly shake the sprayer while in the process of application to prevent the solution from clogging

Pest controlled:

1. Flea beetles on tomatoes and potatoes
2. Anthracnose
3. Bacterial blight
4. Bacterial wilt
5. Black spot
6. Downy mildew
7. Early blight of potato and tomato
8. Late blight on solanaceous crops
9. Powdery mildew
10. Rust

3.5.3 Soil Solarisation

General information

Soil solarisation is a method of controlling soil-borne pests (soil-borne fungi, bacteria and nematodes) without the application of pesticides by placing plastic sheets on moist soil during periods of high ambient temperature. The plastic sheets allow the sun's radiant energy to be trapped in the soil, heating the upper levels. Transparent plastic allows for more effective heating of the soil than black or coloured one. Also, the thinner the plastic the greater the heating will be, though the plastic should be resistant to wind and/or puncture by animals should be avoided.

Soil solarisation is most applicable and viable in arid and semi-arid conditions where hot temperatures prevail during the day time. However, poorly-resourced smallholders may not have the financial resources to invest in plastic mulches nor leaving their restricted land units for a month without cropping.

Solarisation during hot months can increase soil temperature to levels that kill many disease-causing organisms (pathogens), nematodes and weed seed and seedlings. It leaves no toxic residues and can be easily used on a small or large scale. Soil solarisation also improves soil structure and increases the availability of nitrogen (N) and other essential plant nutrients. (Elmore *et al.*, 1997)

How to prepare the soil:

Soil to be solarised must be well prepared by tilling and should be crumbled to a depth of 30cm to 40cm. Solarisation is effective only if done with moist soil. The field must therefore be irrigated until a depth of 50cm to 60cm before mulching. Solarisation is most effective if the plastic is laid as close to the soil surface as possible. Remove weeds, stones and other debris that could puncture the plastic.

Laying the plastic sheet:
Sheets can be laid by hand. The edges of the sheet should be buried in small trenches around the field, or weighed down by sand bags. Plastic can be laid either in complete coverage where the entire field to be planted is covered or strip coverage where only beds or parts of the field are treated.

Strip coverage effectively kills most pests and eliminates the need for deep cultivation after solarisation. It is especially effective against weeds, since the furrows are cultivated. Strips should be a minimum of 75cm wide; beds up to 1.5m wide. Strip coverage can be more economical because less plastic is needed. With strip coverage, however, long term control of soil pathogens and nematodes may be lost because pests in the untreated soil in the rows between the strips can contaminate and re-infest treated areas.

Duration of treatment:
The plastic sheets should be left on the soil for 4 to 6 weeks to allow the soil to heat up to the highest temperature possible. Then, the plastic can be removed. If the soil must be cultivated for planting, the cultivation must be shallow, less than 5cm, to avoid moving untreated soil to the surface.

Solarisation of Seeds and Grains:
Dry grain and seed that has been attacked by grain weevils, borers or moths can be treated as follows:

1. Put affected grain in a black plastic bag and close tightly, closing in at least 50% air space
2. Put the bag in the sun. If the seeds are to be used for planting, insert a thermometer to be sure the temperature inside the bag does not exceed 50°C (the seeds will quickly loose capacity to germinate above this temperature)
3. Leave for a day
4. Check at the end of the day if any insects are still alive. If the sun has been hot enough, the insects will have died at the end of the day. If a few are still alive, repeat the treatment. The grain can then be stored using good storage practices as described under storage pests

3.5.4 Bio-fumigation

General Information

Bio-fumigation is based on incorporating soil amendments (fresh plant mass, manure) into the soil, which will release chemical substances, known as isothiocyanates (ITC's), and is used to suppress soil-borne pests and diseases. Plants from *Cruciferae* family (cabbage, radish, cauliflower etc.) release large amount of these toxic to soil-borne pests and diseases substances - into the soil and are considered the best material for bio-fumigation.

How to do it:

- Incorporate the fresh mass into the soil. This can be done directly if the mass comes from a grown crop or the plant mass is brought from elsewhere onto the plot or field. If the mass is transported to the field, the soil should be well prepared before the incorporation. During transportation and storage of these organic materials in the field, care must be taken not to lose the gases produced from biodegradation, by covering the piles of the bio-fumigant with plastic until the time of application
- A dose of 50t/ha is recommended, although when problems with nematodes or fungi are very serious, 100t/ha should be applied, a dose that can be reduced by choosing a cultivation techniques such as application in furrows
- The bio-fumigant should be distributed uniformly, so that no concentration of pathogens will appear that could create problems for the crop. Once the bio-fumigant is distributed, it should be incorporated immediately into the soil

- Water the field, if possible by sprinkling, until the soil is saturated, although watering can be done by flooding, or drip irrigation can be installed
- Cover the soil surface tightly with a transparent plastic film for at least two weeks to retain the gases produced from the biodegradation of the organic matter. This could be the same plastic as the one used for soil solarisation
- The film is removed 3 to 4 weeks after and the soil slightly removed in order to permit the gases to escape from soil.
- Planting of the intended crop can be done 24 hours later

Using Bio-fumigation against Nematodes
Different mustards (e.g. *Brassica juncea var integrifolia* or *Brassica juncea var juncea*) should be used as intercrop on infested fields. As soon as mustards flower they are mulched and incorporated into the soil. While incorporated plant parts are decomposing in a moist soil, nematicidal compounds of this decomposing process will kill nematodes. Two weeks after incorporating plant material into the soil a new crop can be planted or sown (it takes about two weeks for the plant material to decompose and stop releasing phytotoxic substances = chemicals poisonous to plants) (Eric Wyss, Personal communication).

Mexican marigold, also known as Tagetes, has been successfully used in the control of root-knot nematode in roses by a Kenyan Farmer (Report on ToT for Alternatives to the Use of Methyl Bromide for Soil Fumigation in Brazil and Kenya).

It is recommended to alternate the use of agricultural residues with green manure, especially from brassicae, using 5kg-8kg/ m^2 of green matter, although combinations of legumes and grass can be applied. In the case of the use of green manure cultivated in the same field, fast growing plants should be used to be incorporated at least 30 days after having been planted, to avoid the increase of pathogen populations. Planting mustard after bio-fumigation can serve as bio-indicators of possible phytotoxicity, because the germination of their seeds is sensitive to phytotoxic substances. At the same time they are very sensitive to nematodes and permit the detection of areas in the crop where bio-fumigation is not effective. They act like trap plants, and like bio-fumigants when incorporated into the soil.

In Spain, successful the application of bio-fumigation was achieved in strawberries, peppers, cucurbits, tomato, brassicae, cut flowers, citrus and banana. Bio-fumigation has also been recently applied to Swiss chard and carrot crops. The most utilised bio-fumigants have been goat, sheep and cow manure, and residues from rice, mushroom, brassicae and gardens.

The effectiveness of bio-fumigation in controlling nematodes, fungi, insects, bacteria, and weeds is nearly the same as with the use of conventional pesticides. Bio-fumigation may also regulate viral problems by controlling vector organisms.

(FAO, Global report on validated alternatives to the use of methyl bromide for soil fumigation).

Bio-fumigation against Bacterial Wilt
Since 1999, research on using bio-fumigation for the control of bacterial wilt has been carried out in Australia and the Philippines by the Australian Centre for International Agricultural Research (ACIAR). The Centre and its collaborators have been working to identify suitable brassicas for tropical environments and to evaluate them in the field, initially on experimental farms and more recently on commercial farms and smallholder

farmers' fields. There are many varieties and they differ enormously in the level of disease-suppressing chemicals they produce.

In recent years, Australian banana growers have started growing brassica green manures for nematode control, and in the US, farmers are using mustard green manure crops to replace synthetic fumigation for potatoes with huge cost savings.

Growing radish, mustard and broccoli have reduced bacterial wilt significantly (50-60%) in most of the experiments, though researchers believe the treatment is more effective on sandy soil than on heavy clay soil.

How do we get useful chemicals out of the plant tissue? The most effective way, according to researchers, is to disrupt the plant cells, by freezing or by complete maceration. This will give the best bio-fumigation effect, but equipment to do this is not always available. A field rotavator used for chopping the plant material and incorporating it into the soil is second best. The rotavation effect can be duplicated by hand chopping the plant material before digging it into the soil but this is very labour demanding.

The project also discovered that other large incorporations of green manure will suppress bacterial wilt. An example is mentioned of sweet potato leaves giving good control as well.

In Northern Australia, results in some field trials have been excellent. A plot with a high level infection of bacterial wilt was planted with tomatoes. An untreated block yielded less than 2 tons of tomatoes/ha, while the area where brassica green manure had been applied yielded up to 20 tons/ha of tomatoes and had correspondingly lower levels of bacterial wilt.

3.5.5 Effective Microorganisms (EM)

Effective Microorganisms is a mixed culture of beneficial microorganisms (primarily photosynthetic, lactic acid bacteria and yeast) that can be applied as an inoculant to increase the microbial diversity of any environment. This, in turn, can improve the environment's quality and health, which enhances the growth, yield and quality of crops; the health of aquatic and animal husbandry environments as well as human health.

The concept of inoculating soils and plants with beneficial microorganisms to create a more favourable microbial environment for plant growth has been discussed for decades by agricultural scientists. However, the technology behind the concept of Effective Microorganisms (EM) and its practical application was developed by Professor Teruo Higa at the University of the Ryukyus in Okinawa, Japan.

Professor Higa has devoted much of his scientific career to isolating and selecting different microorganisms for developing beneficial effects on soils and plants. He has found microorganisms that can coexist in mixed cultures and are physiologically compatible with one another. When these cultures are introduced into the natural environment, their individual beneficial effects are greatly magnified in a synergistic fashion.

Note:
EM cultures do not contain any genetically modified microorganisms. EM is made up of mixed cultures of microbial species that are found in natural environments worldwide.

Some of the benefits of EM in agriculture are:

- They promote germination, flowering, fruiting and ripening in plants

- They improve the physical, chemical and biological environments in the soil and help to eliminate soil-borne pathogens and pests. (EM as such is not a pesticide and thus does not contain chemicals that could be construed as such. EM is a microbial inoculant that functions indirectly as a biological control measure in controlling pests and diseases through the introduction of beneficial microorganisms to the plant environment. Pests and pathogens are reduced or eliminated through natural processes by increasing the competitive and antagonistic activities of the soil microorganisms through the use of EM inoculants)
- They enhance the photosynthetic capacity of crops
- They ensure better germination and plant establishment
- They increase the effectiveness of organic materials as fertilisers. Due to these beneficial effects of EM, yields and quality of crops are enhanced.

Effective Microorganisms are also very successfully used in animal systems and have amongst others the following effects:

- They control foul smells in livestock barns and septic tanks
- They decrease the number of flies and ticks
- They protect animals from disease and improve their health
- They decrease stress in animals
- They improve meat quality
- They improve productivity
- They improve animal manure quality (producing good fertiliser quality manure)

Basically EM can be applied in six ways, namely as SAEM, EM5 solution, EM fermented plant extract (FPE), EM Fermented Fish (EM FF), EM Isseki Sancho (EM Insecticide) and EM Bokashi. It is recommended to add Molasses at 1:1 with the EM derivative you use when spraying out into the respective environment. This way, the microbes will get a good head start in their work (are supplied with some food sources) and beneficial microbes that already exist in that environment are supported as well.

1) **Multi EM or Super Activated EM (SAEM)** is produced in multiplying the EM Stock solution through adding molasses and water. This makes it cost effective and is then applied, depending on the situation in a dilution of 1:100 (compost) to 1:1 000 (plants)
2) **EM5** Insect repellent (EM fermented solution) is a fermented mixture of vinegar, spirits (alcohol), molasses and EM. EM5 is an organic insect repellent and is non-toxic. EM5 is used to help prevent disease and pest problems in crop plants and is also beneficial to animals in trusseting hat prevents insects from attacking their skin. It is usually sprayed in a dilution of 1:1 000, and for animals 1:500. It is used mainly to repel insects by creating a distasteful barrier. EM5 also helps control diseases/pest attack by the mechanism of 'competitive exclusion', a form of natural biological control
3) **EM FPE** (Fermented Plant Extract) is a mixture of fresh weeds fermented with molasses and stock EM. It serves as a bioactive supplement of vitamins, hormones and enzymes, which help plants ward off plant pathogens and harmful insects. The cost of making FPE can be very low if you use weeds, but using herbs will improve its quality
4) **EM FF** is a fermented mixture of fish and EM. It is used as a foliar feed and due to the fortified photosynthetic bacteria cultured the plant's fruit sugar content rises and produces very tasty produce with a prolonged shelf life
5) **EM Insecticide** is brewed with EM and

a variety of insecticidal plants, e.g. garlic, chilli, ginger, pepper and is used against strong pests, acting as a contact poison

6) **EM Bokashi.** Bokashi is a Japanese word, which means 'fermented organic matter'. It is made by fermenting organic matter (bran, oilcake, fish meal etc.) with EM. EM Bokashi is an important soil amendment used to increase plant nutrients and the abundance of beneficial microorganisms in the soil

Effective Microorganisms – INSTRUCTIONS FOR USE

EM1

1. EM has a sweet-sour taste & smell (pH below 3.7)
2. It needs to be stored in an airtight plastic container. Gas needs to be released occasionally
3. The best temperature for storage is between 15° and 20°C with little fluctuation (less than 10°C in 24 hours)
4. It needs to be stored away from direct sunlight, preferably in a storeroom
5. Ideally blankets or bubble sheets should be used as an insulator at the top and the sides of the containers. The container should be placed directly onto the ground in summer for coolness and in winter the insulation should be placed under the base of the container as well
6. The beige/white fungi appearing on the surface are beneficial in EM
7. The shelf life for EM1 is 6 months

How to make Activated or Multiplied EM (AEM or Multi EM)

PLEASE NOTE: ONLY MULTIPLY EM ONCE!!!

Multiplications of AEM or Multi EM will be inferior (basically a lactic acid soup), due to uneven ratio of multiplication of the various Microorganisms and will not give you good results!

Materials

- 5% good quality EM1
- 5% pure liquid cane molasses
- 90% clean water
- Borehole drinking water
- City water: containers with city water need to be left open in the sun for 3 days to get rid of the chlorine
- 0.1% pure sea salt, or sea water
- Temperature 20° to 25° C is best (a range from 15° to 37° C is allowed)

Preparation

- Mix the molasses in warm water to dissolve completely
- Mix EM1 into the molasses water
- Fill the container with warm water. Leave a gap at the top with some air
- Mix well
- Seal the container tightly and allow the gas to be released often. With larger quantities use a breather pipe to release the gas, eliminating the need for daily control. For this, drill a hole in the lid of the container, seal a spaghetti tube into it and place the other end into a bottle with water. Now the gas can come out, but no oxygen goes back into the container

Good AEM or Multi EM

- When the Multiplied EM is ready it smells and tastes like the EM1
- It is ready in 7 to 14 days, depending on the temperature
- Favourable pH is below 3.7
- Multiplied EM can be safely stored for 2 months, as long as pH stays below 3.7

Use of AEM or Multi EM

For Plants generally

1. 1:500 to 1:1 000 dilution AEM or Multi EM

2. If used, chlorinated water must be left in open air for half a day

Seeds

Soak seeds in 0.1% EM, small seeds for 30 minutes, large seeds for up to 8 hours. Dry under shade to avoid sticking together. This process promotes faster and even germination as well as healthy growth of plants.

Potatoes/grain etc.

100l/ha in 400l water and three times per season. Best is before or after rain.

Hops

300ł/ha AEM or Multi EM in 1 000l water. Three times per season.

Flowers

Liquid fertiliser dosing system and mist spray in green house. All the tables are cleaned with EM. Geranium, primula, roses.

Vegetables

1: 100 spraying on gardens once per week, alternated with 1:100 FPE.

Aquaculture

1:1 500 (Tilapia) -5 000 (trout) dilution of EM to begin with and can then be maintained at 1:10 000. Spray 1% EM directly onto feed and leave to dry under shade for 4 hours (or until dry). The feed can be used directly afterwards.

Soil

1:100 to 1: 500 dilution of AEM or Multi EM

Compost/Manure

1:100 dilution of AEM or Multi EM 100 to 200l/m^3 (depending on moisture in material).

Slurry

2l/m^3 (1% AEM or Multi EM). Let mature for 4 weeks. It then goes thinner and thinner and does not smell anymore. It is spread even on delicate leguminous plants with no problem at 10m^3/ha. Some farmers add still another dose of EM before spraying out.

Silage

1l/m^3 for grass and 2l/m^3 for maize silage. Best is 35% moisture content. Fermentation is 6 weeks with grass. Leave raw material only for a short time in the open – every day you lose 1% sugar. Then compact quickly

In the stable

Every 3 days with mist sprayer – 10ml/m^2 depending on moisture in the stable. Overhead sprinklers. Add 1:1000 to drinking water

Calf drink

30ml/animal – do not leave it in too long otherwise it curdles

Hoof bath

2% AEM or Multi EM in the walk-through bath, prevents rot and builds beautiful hoofs. Can be left in pan for up to a week

Porkers

If feed mix self-made, 10% AEM or Multi EM is added. Spray in stable as with cows. Liquid feed (whey) per m^3 - 2l AEM or Multi EM. One could also add 3% Bokashi into the grain ration. Alternatively mix 1:1 000 into drinking water

Chickens

From day 1, 10% AEM or Multi EM into growers mix. 3% Bokashi into layers mash. Alternatively mix 1:1 000 into drinking water through nipple drinkers. If they clog up, just flush through with clean water. To prevent mites spray EM5 throughout the house! Before moving chicks into a new house, wash out house with 1:4 to 10% AEM or Multi EM with high-pressure hose. Then and EM chicken manure Bokashi into the shavings

Washing machine
30ml to 40ml into drum. Instead of softener put EM into the little container. Need only 1/3 of washing powder

House cleaning
30ml in a 10 litre bucket

Drinking
5 to10 drops per 300ml, body warm water temperature

Spray
In mist bottle at 1:500 to 1:1 000 onto carpets, as anair refresher, in cupboards etc.

Sewage system
The daily inflow (number) in m^3 is the weekly dose in liters of AEM or Multi EM (e.g. $20m^3$ of sewage will need 20l AEM or Multi EM/ week). It can reduce BOD by up to 90%

For more uses and industrial applications, please contact us!

Other EM Derivatives

1. EM-FPE (Fermented Plant Extract): Bio-active supplement of vitamins, hormones and enzymes. FPE prevents pests & disease of the plants and soil. The cost of making FPE can be very effective if you use weeds, but using herbs will improve its quality and is then similar to EM Insecticide (Isseki-Sancho or 3-in-1)
2. EM 3-in-1 or EM Insecticide: This is a powerful contact poison and although organic and made from known spices, should ideally only be used when there is a problem. It will also harm beneficial insects. However it is often brewed together with the EM5 and sprayed preventatively
3. EM-FF (Fermented Fish): This is a good foliar feed, provides nitrogen to plants in slow release. The use on crops results in fruit sugar content rise and with constant harvest we help by supplementing photosynthetic bacteria and amino acids through EM FF
4. EM-FCM (Fermented Chicken Manure): is a good foliar feed and will provide immediate N and P to the plant in times of shortage from the soil.
5. EM5: is an organic insect repellent and is non-toxic. It is used to help prevent disease and pest problems in crop plants and is also effective for animals to prevent insects from attacking their skin. It is mainly used to repel insects by creating a distasteful barrier. EM5 also helps control diseases/pest attack by the mechanism of 'competitive exclusion', a form of natural biological control
6. Bokashi: Bokashi is a Japanese word, which means 'fermented organic matter'. It is made by fermenting organic matter (bran, oil cake etc.) with EM. EM Bokashi is on one hand an important soil amendment used to increase plant nutrients and the abundance of beneficial microorganisms in the soil on the other a valuable feed amendment and used for livestock between 1 and 3% of their total diet

How to make EM-FPE

Materials

- 5% good quality AEM or Multi EM
- 5% pure liquid cane molasses
- Clean water
- Borehole drinking water
- City water: containers with city water need to be left open in the sun for 3 days to get rid of the chlorine
- Temperature 20°C to 25°C is best (a range between 15°C and 37°C is allowed)
- Container full of fresh weeds, herbs and other plant matter (the Japanese say 'plants with lots of life')

Preparation

- Put the weeds and plants (chopped to between 2cm to 5cm in size) into an airtight bucket or container. Fill the bucket and lightly press down by hand
- Mix AEM or Multi EM and molasses into warm water and pour the solution into the container
- Close the container tightly and install a breather pipe as with AEM or Multi EM if necessary
- Store the container away from the sun in a warm place (20° to 35°C)
- Stir the weeds regularly to release the gas

Good EM-FPE

- Is ready to use in 1 to 2 weeks
- Has a favourable pH of less than 3.7
- Is sprayed in a dilution of 1:1 000 to 1 500
- Can be stored for 1 to 2 months

Use of EM FPE

- Spray on plants at 1:500 to 1:1000
- Spray on soil (to suppress disease) at 1:100 to 1:500

How to make EM Insecticide or EM 3-in-1

Materials

- 3% good quality AEM or Multi EM
- 3% pure liquid cane molasses
- Clean water
  - Borehole drinking water
  - City water: containers with city water need to be left open in the sun for 3 days to get rid of the chlorine
- Temperature 20° to 25°C is best (a range of between 15° and 37°C is allowed)
- 2% by weight chilli
- 2% by weight garlic
- 2% by weight ginger
- 2% by weight black pepper (second grade)
- Should some ingredients be not available locally, they can be replaced with a herb/ spice of similar action

Preparation

- Put the spices (chopped or minced) into an airtight bucket or container.
- Mix EM and molasses into warm water and pour the solution into the container.
- Close the container tightly and install breather a pipe as with AEM or Multi EM if necessary
- Store the container away from the sun in a warm place (20° to 35°C)
- Stir regularly to release the gas

Good EM 3-in-1

- Is ready in 1 to 2 weeks
- Has a favourable pH of less than 3.7
- Is sprayed in a dilution of 1:1 000 to 1 500
- EM 3-in-1 can be stored up to 6 months

Use of EM 3-in-1

- Spray on plants at 1:500 to 1:1 000
- Mix with EM5 50/50 as preventative spray

How to make EM-FF

Materials

- 3% good quality AEM or Multi EM
- 3% pure liquid cane molasses
- Clean water
- Borehole drinking water
- City water: containers with city water need to be left open in the sun for 3 days to get rid of the chlorine
- Temperature 20° to 25°C is best (a range of between15° to 37°C is allowed)
- 10% by volume crushed fish or fishmeal, preferably of blue skinned fish, e.g. sardines

Preparation

- Place fish or fishmeal (crushed or chopped into 2cm chunks) into an airtight bucket or container
- Mix EM and molasses into warm water and pour the solution into the container
- Close the container tightly and install breather pipe as with AEM or Multi EM if necessary
- Place the container in the sun. This is the

only time EM is placed into the sun for fermentation. We are encouraging the activation of the photosynthetic bacteria
- Stir the brew regularly to release the gas

Good EM-FF
- Is ready in 1 month
- Has a pH of between 6 and 7
- Spray in a dilution of 1:1 000 to 1 500. If it is too smelly mix with 25% AEM or Multi EM just before spraying
- Can be stored for 6 months

Use of EM FF
- Spray on plants at 1:500 to 1:1 000
- 1:300 inoculation into the soil

How to make EM FCM
Materials
- 3% good quality AEM or Multi EM
- 3% pure liquid cane molasses
- Clean water
  – Borehole drinking water
  – City water: containers with city water need to be left open in the sun for three days to get rid of the chlorine
- Temperature 20° to 25°C (a range of between 15° to 37° C)
- 20% by volume chicken manure
- 1% by volume Bokashi

Preparation
- Put chicken manure into an airtight bucket or container
- Add bran Bokashi
- Mix EM and 3% molasses into warm water and pour the solution into the container
- Close the tightlyand install breather pipe as with AEM or Multi EM if necessary.
- Store the container away from the sun in a warm place (20° to 35°C)
- Stir regularly to release the gas

Good EM FCM
- Is ready in 1 to 2 weeks.
- Has a favourable pH of 5 to 6
- Spray in a dilution of 1:1 000 to 1 500
- Can be stored for 1 to 2 months

Use of EM FCM
- Spray on plants at 1:500 to 1:1 000
- 1:300 inoculation into the soil

How to make EM5 –Insect repellent
Materials
- 10% good quality AEM or Multi EM
- 10% natural grape vinegar (not spirit vinegar, which is derived from coal)
- 10% pure liquid cane molasses
- 10% alcohol (above 40%)
- 60% good clean water

Preparation
- Mix the molasses in warm water to dissolve completely
- Add alcohol and vinegar to the molasses water and stir
- Pour into the container
- Add AEM or Multi EM last
- Fill the container with water; leave a little gap of air
- Mix well
- Seal the container tightly and release the gas often or install breather pipe as with AEM or Multi EM

Good EM5
- Is ready when the strong molasses smell has disappeared and is a good blend with quite a strong alcohol smell
- Takes a little longer to mature, between two and four weeks
- Has a pH of around 3.6
- Can be stored for 6 months

Use of EM5

- Spray on plants at 1:500 to 1:1 000
- Mix with EM 3-in-1 50/50 as preventative
- Spray on animals against tick, flee etc. infestation 1% to 10%

How to make EM Bokashi

There are many different kinds of Bokashi for various applications. Below is a recipe, which can be used universally, is simple and cheap to make. The liquid we use to mix into the bran varies because the moisture content of the bran also varies. The quantities below are therefore a guide:

Materials

- 3% good quality AEM or Multi EM
- 3% pure liquid cane molasses
- About 30% vol. good clean water
- 125% to 150% by volume of container wheaten bran, maize bran or any other available bran
- An airtight plastic bucket

Preparation

- Mix the molasses in warm water to dissolve completely
- Add AEM or Multi EM
- Depending on quantity empty bran into a wheelbarrow or onto a clean concrete floor
- Spray EM/molasses mix onto the bran, with a backpack sprayer or watering can. Mix bran thoroughly with hands or spades. Continue spraying, while someone else mixes
- The moisture content is correct – at approximately 35% – when you take a handful of the bran and squeeze in your hand. If liquid drips out, the mixture is too wet. When you open your hand you want the 'sausage'to hold its form, open slightly, but not crumble apart. If it crumbles you need to add some more liquid
- Add the bran to the bucket in layers of about 20cm at a time and then compact it with your fists or trample with your feet. You want to get all the air out
- When the bucket is full cover with a few layers of newspaper, to absorb condensation and seal the lid tightly

Good Bokashi

- Takes 4 to 8 weeks to mature
- Has a sour smell, a bit like pickles when it is ready
- Can be stored up to 6 months

Use of EM Bokashi

- Improves soil at 200gr/sqm
- Feed: 200g/animal/day. Small animals 100g to 150g/animal/day (between 1% and 3%)

Resources and further reading: There are numerous good quality references available.

The following are useful:
1) For more information on **Push Pull:**
http://www.push-pull.net
2) For more information of **biological controls in the tropics**, especially in Africa:
http://www.icipe.org
3) **Citrus pests and their natural enemies** provides detailed description of citrus pests in Australia. The information is useful for a range of crops
4) **Citrus pests and their natural enemies:** integrated pest management in Australia / edited by Dan Smith, G.A.C. Beattie & Roger Broadley,1996
http://trove.nla.gov.au/version/9741383
5) **Citrus pests – a field guide** is a companion to Citrus pests and their natural enemies and is designed to help with identification
6) **Citrus pests: a field guide: a companion to citrus pests and their natural enemies: integrated pest management in Australia** / edited by Dan Smith ... [et al.]. 1997
http://trove.nla.gov.au/version/29353538

7) **Cotton Pests and Beneficial Guide.** Cotton Research and Development Corporation, PO Box 282, Narrabri, NSW 2390
8) **The Good Bug Book** provides detailed information for organic and IPM systems. Compiled by the Australasian Biological Control Group. 1995
9) **Natural Enemies Handbook**, University of California. This is an excellent resource. Australasian Biological Control (ABC) – Association of Beneficial Arthropod Producers. Information on beneficial insects and mites available in Australia.

Suppliers of pesticides and other products authorised for use in organic agriculture
1) Agro-Organics: *www.agroorganics.co.za*
2) Talborne Organics: *www.talborne.co.za*
3) Valent Biosciences: Contact Somerset West at 021 8514163 OR Philagro South Africa office in Pretoria at 012 3488808
4) Insect Science SA (Pty)Ltd: *www.insectscience.co.za*
5) Microbial Solutions: *www.microbial.co.za*
6) Dagutat Science: *e-mail dagutath@xsinet.co.za*
7) Plant Health Products (Pty) Ltd: *www.plant-health.co.za*
8) Madumbi Sustainable Agriculture: *www.madumbi.co.za*
9) The Real IPM (SA) Pty Ltd: *www.realipm.com*
10) Genuine EMRO EM 1 (Effective Microorganism) supplier in Namibia – Gentech – *herbygentech@iway.na*

Product names of pesticides, fertilizers and various tools authorised for use in organic agriculture and their main uses
1) Insecticides, fungicides and nematicides
Dagutat Science
E-mail: *dagutath@xsinet.co.za* for more information

Nematode control:
The following microbial formulations are available:
– Romulus
Active ingredient: *Trichodermaharzianum isolate* DB 104 (fungus)
– Spartacus
Active ingredient: *Beauveria bassiana* isolate DB 105 (fungus)

- Romulus and Spartacus attack nematodes directly
- The fungus hyphae penetrate the nematode through an opening, excretes enzymes which enables it to utilise the nematodes as a food source in nature
- Both Spartacus en Romulus stimulates root development

For more information send an e-mail to *dagutath@xsinet.co.za*

Powdery mildew and Botrytis control:
The following microbial formulations are available:
1) Shelter
Active ingredient: *Bacillus subtilis* isolate DB 101 (bacterium)
2) Artemis
Active ingredient: *Bacillus subtilis* isolate DB 102 (bacterium)
3) T-Gro
Active ingredient: *Trichoderma harzianum* isolate DB 103 (fungus)
4) Bismarck
Active ingredient: *Microbacterium marytipicum* isolate DB 107 (bacterium)

Plant Health Products (Pty) Ltd:
1) Eco-T
A fungal inoculant for the control of crop root diseases and for enhanced plant growth. Product contains spores of Trichoderma harzianum strain kd
2) Eco-77
A fungal inoculant for the protection of

pruning wounds and for protection against Botrytis infection. Product contains spores of Trichoderma harzianum strain B77
3) Eco-Bb
A fungal inoculant for controlling whitefly and for suppressing red spider mites. Product contains spores of Beauveria bassiana strain R444

Valent Biosciences, div. of Philagro South Africa(Pty)Ltd:
1) Dipel DF (IPM)
Microbial formulation (biological agent) containing Bacillus thuringiensis var. kurstaki for the control of lepidopterous larvae (leaf-eating caterpillars)
2) Vectobac WG(IPM)
Microbial formulation (biological agent) containing Bacillus thuringiensis subsp. israelensis for the control of mosquito and fungus gnat larvae

Agro-Organics: *www.agroorganics.co.za*

Plant foods and fertilisers
For product names visit the websites of:
1) Talborne Organics: *www.talborne.co.za*
2) Agro-Organics: *www.agroorganics.co.za*
3) Microbial Solutions: *www.microbial.co.za*
4) Plant Health Products (Pty)Ltd:
www.plant-health.co.za
5) Madumbi: *www.madumbi.co.za*
6) Soil-inoculants (microbial)
Microbial Solutions: *www.microbial.co.za*
7) Altius Environmentals:
www.environmentals.co.za
8) Plant Health Products (Pty) Ltd:
www.plant-health.co.za
9) Madumbi: *www.madumbi.co.za*

Insect Traps and Pheromones:
1) Insect Science SA (Pty) Ltd:
www.insectscience.co.za
2) Beneficial insects and nematodes Du Roi Integrated Pest Management at
www.duroibugs.co.za
or Tel: +27 (0)15 345 1572