Integrated pest management in vegetable production: A guide for extension workers in West Africa

B. James, C. Atcha-Ahowé, I. Godonou,
H. Baimey, G. Goergen, R. Sikirou and M. Toko

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INRAB, Cotonou, Benin was created in 1992 and has the following aims:
- to contribute to the development of a national policy of research in Benin
- to conceive, and carry out the research programmes and related studies which are of concern to the agricultural sector, either at its own initiative, or at the request of the government
- to ensure the transfer of research outputs to end-users
- to ensure in general all research activities leading to the development of agricultural sciences and their application
- to coordinate at national level all agricultural research activities
- to contribute to training in agricultural research and in development
- to publish and disseminate the results of its work and more generally, to contribute to the development of scientific information.

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- holistic and ecological approaches to the development of IPM technologies
- effective communication among stakeholders for informed IPM decision-making
- farmers' uptake of IPM technologies for larger, healthier harvests
- public awareness of IPM and its impact on sustainable agriculture.

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Foreword

Indigenous and exotic vegetables are central to most nutrition, food security and poverty reduction programmes around the world. However, in most of West Africa, the economic opportunities offered by vegetables are often undermined by production and trade constraints (i.e. pest damage, inappropriate pesticide usage, absence of environmental safeguard policies and/or stringent food safety standards). Extension workers and, in places, farmers groups and local community organizations, are working towards helping farmers to increase their yields in sustainable ways that create wealth and reduce the risks to productivity.

All too often, extension workers do not know the cause of common pest problems in the crops they work with. Pest problems usually arise when the biological, ecological and sociological processes which underpin agriculture are disrupted. This guide helps to fill that information gap. It is one of many responses by the International Institute of Tropical Agriculture (IITA) which enables such workers to develop and use technologies. It focuses on accurate identification and better understanding of biodiversity in the development and application of Integrated Pest Management (IPM) options against vegetable pests. IPM is a knowledge-intensive approach to enhance profitability of agricultural systems, while minimizing threats to human health and the environment.

The technical knowledge and skills in this guide can be used to look for, develop and apply effective vegetable IPM options. The IPM options outlined here are in harmony with the environment, sustainable, simple to apply, and cheap to maintain. The guide addresses IITA's strategic aim of increasing the quality and usefulness of IPM research in support of reducing food security and poverty. It draws heavily on IITA's experiences in Africa, with a particular emphasis on vegetable agroecosystems in Benin. Given the substantial economic costs of pest infestations in vegetable agroecosystems, the use of this guide in Africa is expected to improve incomes and overall agricultural productivity in the long-term.

Peter Hartmann
Director General
International Institute of Tropical Agriculture
March 2010

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The guide is based on the practical experiences of staff working on a vegetable pest management project at the International Institute of Tropical Agriculture (IITA). This project was a partnership between IITA, the Swiss Agency for Development and Cooperation (SDC) and national agricultural research and extension systems (NARS), including local non-governmental organizations (NGOs) in Benin. The project:

- Trained vegetable growers in urban and peri-urban areas to correctly identify and control major vegetable pest and disease problems
- Developed biologically-based vegetable pest control options for use in integrated pest management (IPM) programmes
- Strengthened local IPM capacity of extension workers and farmers to better understand and manage vegetable pest problems.

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Introduction

The specific examples in this guide are for Benin, but the methodologies and general information are applicable to other vegetable production sites in West Africa. Other countries can adapt the methodologies and develop similar country-specific information.

Vegetables are important components of daily diets in Africa and important sources of income, especially in urban and peri-urban areas. As many as twenty different types of indigenous and exotic vegetables are grown at major vegetable production sites around West Africa (Figure 1). These crops provide a cheap source of proteins, vitamins and other elements essential for human health and wellbeing. In West Africa, vegetables are commonly grown in the rainfed upland ecologies and in lowland ecologies such as bolilands, riverine grasslands and inland valley swamps. Agroecosystems in these various ecologies offer great opportunities for commercial production of vegetables in West Africa.

Vegetable production for urban and peri-urban areas in West Africa is popular in rainfed upland ecologies. Rainfed upland ecologies occur on hillsides, usually above

Figure 1. Vegetable production at a peri-urban site in Benin. (Photo: B. James/IITA)

floodlines and have well-drained soils which are not usually covered by standing water. The vegetation is dominated by bushes of perennial shrubs and trees, with minimal grass cover. Vegetables are usually planted early in the rainy season, either by direct seeding or transplanting of seedlings. They are frequently intercropped with other staple food crops (e.g. rice), or planted as sole crops following the harvest of any other crop. Commercial farmers use irrigation systems that allow year-round production in upland ecologies, while smallholder farmers rely on rain and soil water to water their seasonally-grown crops.

Bolilands are large pan-like depressions of land which are naturally flooded by rainwater and freshwater streams. The soil is often clay loam with silt deposits and usually has a large amount of humus on the surface. The vegetation is dominated by grasses. In bolilands, rice is planted either by direct seeding just before the soil is flooded in the rainy season, or by transplanting after the soil is flooded. Vegetables are planted on small mounds left on the bolilands after the rice is harvested at the end of the rainy season.

Inland valley swamps are flooded by overflow from freshwater rivers or streams and rainwater runoff from surrounding hills. The intensity of flooding depends on the duration of the rainfall, the season and on the type of topography. The water level can be artificially controlled so vegetables can be grown on the bunds which separate the plots of rice in these swamps.

Riverine grasslands are alluvial plains which run along the lower parts and mouths of freshwater rivers, and tend to be flooded to significant depths during the rainy season. The natural vegetation is dominated by grasses. The rice plants which are transplanted before flooding grow as floating plants in the waterlogged conditions. In the months prior to flooding, these alluvial plains are important vegetable production sites.

Vegetable agroecosystems

Vegetable agroecosystems comprise a dynamic mix of biotic (living) components, abiotic (non-living) components and the interactions within and between them. Any change in one component or interaction is likely to affect another component or interaction. The reactions of agroecosystems to change can potentially be disastrous to farming communities, and may not be entirely predictable. In order to achieve good vegetable pest management, the vital components of agroecosystems should be correctly identified, their interrelationships fully understood, and the agroecosystem treated as a functional unit (Box 1).

Box 1. Components of vegetable agroecosystems

Abiotic components

- Soil and water (Figure 2) – provide the germinating media for seeds and general growth conditions for vegetables and other plants
- Sunlight, day length, temperature and humidity – provide the additional conditions necessary for healthy plant growth and high yields – influence the development of insects, mites, fungi, bacteria and weeds
- Wind – helps to disperse insects, mites, fungi, bacteria and weeds
- Mineral fertilizers – promote plant growth and increase yields
- Chemical pesticides – are applied to kill pests.

Biotic components

- Vegetables and other crops in the field
- Weeds – compete with vegetable crops for light, water and nutrients - serve as alternative hosts and sources of pest spread – provide specialized food e.g. nectar for pollinators and adults of other insects
- Insects (Figure 3) – mites, fungi, bacteria and viruses which damage crops
- Insects – mites, nematodes, fungi, bacteria and viruses which feed on and kill other insects and mites
- Insects and mites – which pollinate plants.

Interactions

- Intraspecific competition between individuals of the same species for sunlight, water, food, mates and shelter
- Interspecific competition between individuals of different species for sunlight, water, food and shelter
- Feeding by insects, mites, fungi, bacteria, and viruses on vegetables, other crops and weeds
- Feeding by insects and mites on other insects and mites (Figure 4)
- Infection of plants, insects and mites by bacteria, fungi and viruses, which cause diseases in plants and animals
- Influences of abiotic factors on the development and spread of insects, mites and disease-causing agents
- Crop cultivation and management methods and their agronomic implications
- Beneficial and adverse effects of agrochemicals on the environment.

Figure 2. Irrigation at a peri-urban vegetable site in Benin. (Photo: B. James/IITA)

Figure 3. Aphid *Lipaphis erysimi*, a cabbage pest. (Photo: G. Goergen/IITA)

Figure 4. Predatory mite (left) on pest mite (right) – called a phyoseiid. (Photo: G. Goergen/IITA)

Crop types

The vegetable plant is the central component of the agroecosystem. Vegetables can be grouped according to the part of the plant that is consumed and/or sold.

Leafy vegetables

The common leafy vegetables grown in West Africa are the African garden eggplant, amaranth, cabbage and lettuce. There are two common types of African garden eggplant, which are both indigenous to Africa. One is *Solanum macrocarpon* (Figure 5), whilst the other is *S. aethiopicum*. *Solanum macrocarpon* is grown mainly for its succulent leaves, but in some communities the bitter fruits are also eaten. *S. aethiopicum* is mainly cultivated for its fruits. The edible parts of both *S. macrocarpon* and *S. aethiopicum* are nutritious and contain carbohydrate, cellulose and calcium, fat, protein and water.

Amaranth, *Amaranthus cruentus* (Figure 6), is grown for its leaves which are rich in beta-carotene, calcium, iron, protein, vitamin C and water. Cabbage, *Brassica oleracea* (Figure 7), is native to temperate regions of the world. It is called the head cabbage because the immature leaves cluster up into a spherical ball or 'head', which is the part normally marketed and consumed. The leaves contain some carbohydrates, proteins and various essential elements e.g. calcium, iron and vitamin C as well as water. Lettuce, *Lactuca sativa* (Figure 8), is indigenous to the Mediterranean region and occurs in four groups of varieties. The plant is cultivated for its succulent leaves which are used in salads. Lettuce leaves contain a high proportion of water with some calcium, proteins and vitamins.

Figure 5. The African garden eggplant, a leafy vegetable. (Photo: B. James/IITA)

Figure 6. Amaranth, a leafy vegetable. (Photo: B. James/IITA)

Figure 7. Cabbage, a leafy vegetable. (Photo: B. James/IITA)

Figure 8. Lettuce, a leafy vegetable. (Photo: B. James/IITA)

Figure 9. Tomato, a fruit vegetable.
(Photo: B. James/IITA)

Figure 10. Pepper, a fruit vegetable.
(Photo: B. James/IITA)

Figure 11. Carrot, a root vegetable.
(Photo: B. James/IITA)

Fruit vegetables

The most popular fruit vegetables grown in West Africa are the tomato, pepper and aubergine. Tomato, *Lycopersicum esculentum* (Figure 9), which originates from the Andes in South America, is grown for its fruits. The shape of the fruit differs according to the variety. Tomato fruits can be consumed raw or cooked. Tomato fruits contain a lot of water with calcium, carbohydrate, carotene, iron, niacin, riboflavin, thiamine, protein and vitamins.

The sweet pepper or pepper, *Capsicum annuum* (Figure 10), is native to Central America. It occurs in two groups of varieties. Unlike most vegetables, pepper is a relatively long duration crop. Both immature and fully mature fruits are marketed and consumed. The fruit contains plenty of water with some carbohydrates, protein, minerals and vitamin C.

Root vegetables

Carrot, *Daucus carota* (Figure 11), a crop native to Asia, is the most common root vegetable grown across West Africa. It is cultivated for its swollen roots, which are rich in beta-carotene. The roots also contain a large amount of water as well as carbohydrates, minerals and protein.

Vegetable plant production

Depending on market demand and availability of water to irrigate plots, vegetables can be grown all year round. The crops are grown in monocrops, intercrops and crop rotation schemes. Commercial production sites are commonly located near to markets, e.g. in urban and peri-urban areas.

Crop yield

Depending on the vegetable crop type, the leaves, fruits, and roots constitute the yield and provide both food and income to farmers. Field workers and farmers need to be aware of two different types of yield in order to fully understand the purpose of crop production and pest management measures. The two types of yield are maximum or potential attainable yield, and actual yield (Figure 12).

Maximum attainable yield is the yield obtained from crops grown in experimental plots and field conditions with the full use of improved technologies and inputs. It is the highest yield possible from a particular variety cultivated under the ideal conditions.

Actual yield is the yield obtained from crops cultivated under farmers' conditions using the same varieties used in experimental plots. Actual yields are often less than attainable yields.

The difference between attainable and actual yield is due to a variety of environmental factors which include soil type, crop variety, agronomic practices, weather and pests. Agricultural research, extension and training activities aim to find ways to increase actual yields towards attainable yields, for example by manipulating field and environmental factors which reduce yields. The overall objective of vegetable pest management is therefore to prevent, reduce and maintain the effect of pests at levels where they cease to act as constraints to the achievement of higher actual yields (Figure 12). It is in this way that pest management interventions 'increase' yields.

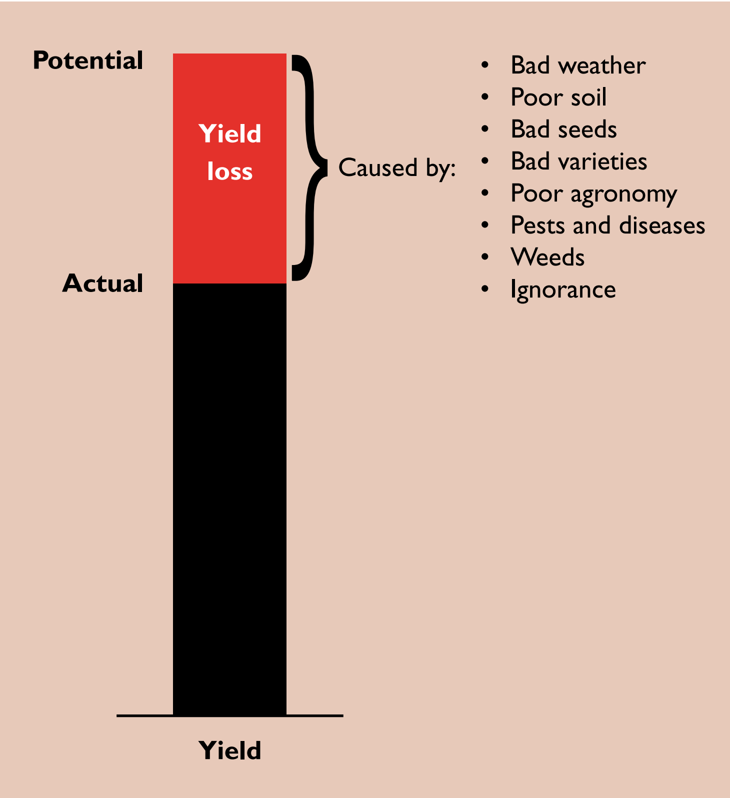


Figure 12. Yield types and causes of yield loss. (B. James/IITA)

Figure 13. Tomato planted on flat land.
(Photo: B. James/IITA)

Figure 14. Lettuce planted on ridges.
(Photo: B. James/IITA)

Land and seed bed preparation

The most suitable sites for vegetable production are flat and sunny areas with light, well-drained soil which is rich in humus and not prone to water logging. These conditions help to promote the establishment of good nurseries and seedling health for excellent vegetable crop growth. Farmers break and loosen up the soil by ploughing, and remove stones and debris to allow sufficient aeration, moistening and drainage of the soil. This promotes good root growth. Removal of plant debris also helps to limit the occurrence of weeds and other pests which are carried over from the previous season.

Vegetables are often planted on flat land (Figure 13) in areas that are unlikely to be waterlogged or flooded. Planting on flat land is also common where the soil is rich in nutrients. In areas that are likely to be waterlogged, or where the soil is poor in nutrients, farmers heap the top soil into mounds or ridges on which they plant vegetables. The mounds of soil raised above ground level are commonly referred to as 'beds' (Figure 14).

Planting

Except for exotic vegetables, (e.g. beetroot, cabbage, carrot, cucumber and lettuce), most farmers produce their own vegetable seeds from their fields or they collect seeds from other farmers' fields. Large-scale farmers do not self-supply and buy certified seeds from seed companies and national seed services. Vegetables are planted by direct sowing of seeds (e.g. amaranth and carrot) or by transplanting seedlings from nurseries (e.g. African garden eggplant, cabbage, lettuce and tomato). In direct sowing, seeds are broadcast on seed beds and harrowed in, or sprinkled in rows and covered up with soil, and left undisturbed to germinate. In transplanting, farmers select vigorous and disease-free seedlings at the right growth stage and transplant them. Table 1 summarizes vegetable planting and soil fertilisation practices in Benin. If the crop is harvested by uprooting of whole plants (e.g. in amaranth, carrot and radish), the seedlings are usually transplanted closer to each other than when the crop will be harvested by ratooning. Planting dates are usually adjusted in response to market demands e.g. in readiness for festive seasons. Planting during the peak of the rainy seasons is uncommon so as to avoid flooding of vegetable beds.

Intercropping

Farmers frequently intercrop vegetables on the same bed (Figure 15). A single bed can hold as many as five different vegetables. Intercrops can be economically more profitable than sole crop vegetables. Intercropping increases farmers' income per unit of land and labour and helps to maintain good soil moisture and reduce the incidence of weeds and other pests on vegetables.

Figure 15. Vegetables planted on flat land, lettuce and onion intercropped. (Photo: B. James/IITA)

Ratooning is a method which leaves the lower parts of the plant along with the root uncut at the time of harvesting to give the **ratoon** or the stubble crop. The main benefit of ratooning is that the crop matures earlier in the season. Ratooning can also decrease the cost of preparing the field and planting.

Crop rotation

Crop rotation enables farmers to maintain land under continuous cultivation by planting with one crop after another in successive seasons. The practice also helps farmers respond to seasonal market demands for certain crops. Where a rotation crop is a non-host plant of a pest that damaged a previous crop, crop rotation helps to control that pest by breaking its life cycle. Good knowledge of crop susceptibility to pests is therefore essential in the use of crop rotation for pest management. This is particularly the case with species of root-knot nematodes which attack a wide range of vegetables including the most economically important crops grown in many localities. The wide range of host plants of the root-knot nematode makes it difficult to identify suitable crop rotation schemes for this pest, especially at sites under year-round vegetable production.

Soil fertility

Soils nourish vegetables with mineral nutrients for vigorous, succulent and healthy growth; but continuous production of vegetables can deplete soil nutrients at production sites. Vegetable farmers use organic and mineral fertilizers to help soils to recover from nutrient losses, and in some cases, reduce pest problems. Both organic (composed of decayed plant/animal material), and inorganic fertilizers (composed of chemicals and minerals), improve soil fertility by adding nutrients to the soil, and are used in a number of different ways.

Mulching, for example, involves mixing plant materials into the soil during land preparation, or covering the bases and rows of the crops with dry grass or plastic sheets after planting. Dry grass or plastic sheets serve as physical barriers between the soil and the environment so the plant residues rot into the soil and increase its organic matter content. Plant foliage mixed into the soil help conserve moisture, suppress weeds, and reduce the spread of plant pathogen spores onto vegetable foliage through water or soil splashes.

Farmers use farmyard manure or humus from compost of plant residues as organic fertilizers. They avoid scorching of the plants by first thoroughly mixing the farmyard manure with soil or water. Where soils are poor, leafy vegetables such as African garden eggplant, amaranth, cabbage, and lettuce will require additional levels of nitrogen and potassium (provided by inorganic fertilizers). High levels of nitrogen delay the onset of flowering and thereby favours leaf production. Table 1 summarizes the type, quantity and application timing of organic and mineral fertilizers.

Table 1. Planting and soil fertilization practices in vegetable production in Benin.

Crop	Seedling stage at transplanting	Seedling spacing	Fertilizer application
African garden eggplant	Use seedlings at 5/6 leaf stage; this growth stage is reached 30–40 days after sowing in nurseries.	Transplant seedlings in rows with a spacing of 40 cm to 60 cm between plants in a row, and between rows. If leaf harvest is by ratooning, use seedling spacing of 30 cm between rows and plants.	Apply mineral fertilizer at the ratio of NPK[1] 5:3:3 with 40% of nitrogen (N) as top dressing. In soils that are particularly deficient in potassium (K), use 400 kg/ha of a compound fertilizer 10:10:20 NPK[2] or organic matter applied at the rate of 20–40 tonnes/hectare (t/ha) for good leaf yield.
Amaranth	Use seedlings at 3 weeks after sowing in nurseries.	If leaf harvest is by uprooting whole plants, broadcast seeds at high density on the seed bed or transplant seedling with a spacing of 10 cm between plants and between rows. If leaf harvest is by ratooning, use seedling spacing of up to 20 cm between plants and between rows.	Apply mineral fertilizers at the ratio of NPK 1.5:1.5:2. Split the application into basal dressing (40% N, 100% P and 40% K) and top dressing at 3, 6 and 9 weeks after transplanting. Mulch manure into the soil at a rate of 10–20 t/ha during soil preparation to get good leaf yield.
Cabbage	Use seedlings at 5/6 leaf stage; this growth stage is reached 25–35 days after sowing in nurseries.	Seedlings are best transplanted in rows with spacing of 30 cm to 60 cm between plants in a row and between rows. The spacing depends on the size of cabbage head required.	Mulch manure into the soil at a rate of 20 to 30 t/ha during soil preparation. Apply chemical fertilizer NPK (ratio: 1:1:2) by splitting it into basal dressing (40% N, 100% P and 40% K) and top dressing at 20 to 35 days after transplanting
Lettuce	Use seedlings at 4/5 leaf stage.	Plant seedlings in rows at 15 to 20 cm between plants in a row and 0.4 m between rows.	Mulch manure into the soil during land preparation. In dry regions, lettuce may require 10–15 t/ha of manure, 150 kg of ammonium phosphate and 300 kg of sulphate potassium before planting. Apply urea at 100 kg/ha at establishment, and 100 kg/ha 15 days later.
Tomato	Use seedlings at 5/6 leaf stage; this growth stage is reached 25 to 45 days after sowing	Plant seedlings in rows at up to 1 m between plants and 40 cm between rows.	Mulch manure into the soil at a rate of 20–30 t/ha at seed bed preparation. Apply NPK: 1:1:2 by splitting into basal dressing (40%) and 20% top dressing at 2, 5, 8 and 11 weeks after transplanting.

1 N-P-K or NPK represent three different compounds: Nitrogen, Phosphorus, and Potassium which make up the fertilizer.

2 The three numbers listed on fertilizer labels correspond to the percentage of these materials found in the fertilizer.

Figure 16. Adult of the cotton bollworm, *Helicoverpa armigera*, female. (Photo: G. Goergen/IITA)

Figure 17. Red mites, *Tetranychus* spp. (Photo: G. Goergen/IITA)

Figure 18. The fungus, *Colletotrichum fuscum*, on vegetable leaf. (Photo: G. Goergen/IITA)

Figure 19. Female of the root-knot nematode, *Meloidogyne* sp. (Photo: G. Goergen/IITA)

Vegetable plant protection

At vegetable production sites, crop diversity, cropping patterns, and certain plant production practices attract a wide range of organisms (bacteria, fungi, insects, mites, parasitic nematodes and viruses) which can be beneficial or harmful to the plant.

Pests

A pest is any organism that injures or damages crops, livestock and people to cause food and income losses and diseases. The term 'pest' refers to the role of any organism to aggravate hunger, poverty and disease. The term 'pest' is, therefore, more socioeconomic than biological, as it relates mainly to the social and economic aspects of human activities. An organism is not a pest in its natural habitat (e.g. insects in wild grasses and natural vegetation), but as soon as it comes into conflict with people and peoples' interests (e.g. insects in cultivated crops), it is treated as a pest. Table 2 lists groups of organisms which can be pests of crops or of stored produce.

The term 'pest' is usually reserved for arthropods and other animal groups. The term 'vector' is used to describe pests that transmit disease-causing organisms to crops, humans and livestock. Microorganisms which cause diseases in plants are usually referred to as 'plant pathogens'. Weeds are pests that are normally considered to cause agronomic problems.

Table 2. Pests of vegetables.

Arthropods – insects (Figure 16) and mites (Figure 17) which feed on plants and/or transmit disease-causing microbes
Microorganisms – fungi, bacteria and viruses which cause diseases in plants (Figure 18)
Molluscs – snails and slugs which feed on plants
Plant parasitic nematodes – which feed on roots and other plant parts (Figure 19)
Vertebrates – rodents and birds which feed on plants
Weeds – compete with crops for space, soil moisture, soil nutrients and sunlight needed for healthy growth of plants

Generally, in this guide, the term 'pest' refers to any organism that damages crops, livestock, and people to cause food and income losses and diseases. The focus of this guide is on pests that are insects, mites, plant pathogens, plant-parasitic nematodes to weeds in the field. Where emphasis is needed, this guide specifies non-arthropod pests as plant pathogens, vectors and weeds.

Natural enemies

Many organisms found on vegetables prey and/or reproduce on other species. They are known as natural enemies (Figures 20 to 27). Common natural enemies of pests are parasitoids, predators and entomopathogens (Box 2).

Box 2. Natural enemies of pests

Parasitoids. Parasitoids are natural enemies that kill and control pests by living and growing inside them. Parasitoids are mainly tiny wasps (Figure 20) or flies which lay their eggs inside or on the pests. The eggs hatch into larvae which eat the internal tissues of the pest organism, grow inside and kill the pest. The body of the dead pest does not rot, but becomes hard. This hardened body is called a 'mummy' (Figures 21 and 26). The adult parasitoids hatch out of the mummy and kill more pests by laying eggs into them.

Predators. Predators are natural enemies that kill and control pests by attacking and feeding on them. Most predators of insect and mite pests are usually other insects and mites, e.g. ladybird beetles (Figures 22 and 23), hoverflies (Figures 24 and 25), and predatory mites called phytoseiids (Figure 4).

Entomopathogens. Entomopathogens are natural enemies which kill and control insects and mites by causing diseases in them. When the host insect or mite dies, the cadaver is in the form of a 'mummy' (Figure 27). Examples of entomopathogens are species of certain bacteria, fungi, nematodes, protozoa or viruses. Entomopathogens are the active ingredients in commercial biopesticides. Biopesticides consisting of bacterial or fungal spores are the most commonly available products. Biopesticides are often applied in a similar way to chemical pesticides; but the 'live' ingredients (e.g. fungi) in the biopesticides reproduce, so they provide continuous pest control and therefore don't require further applications.

Figure 20. Adult parasitoids of aphid pests. (Photo: A. Staverløkk/Bioforsk)

Figure 21. Parasitoid 'mummies' of aphid pests. (Photo: A. Staverløkk/Bioforsk)

Figure 22. Adults of the predatory ladybird beetle, *Cheilomenes sulphurea*. (Photo: A. Staverløkk/Bioforsk)

Figure 23. Larva of the predatory ladybird beetle, *Cheilomenes sulphurea*. (Photo: A. Staverløkk/Bioforsk)

Figure 24. Adult male of the predatory hoverfly, *Ischiodon aegyptius*. (Photo: A. Staverløkk/Bioforsk)

Figure 25. Larva of the predatory hoverfly, *Ischiodon aegyptius*. (Photo: A. Staverløkk/Bioforsk)

Figure 26. 'Mummy' of the parasitoid *Cotesia* sp., natural enemy of diamond back moth, *Plutella xylostella*. (Photo: G. Goergen/IITA)

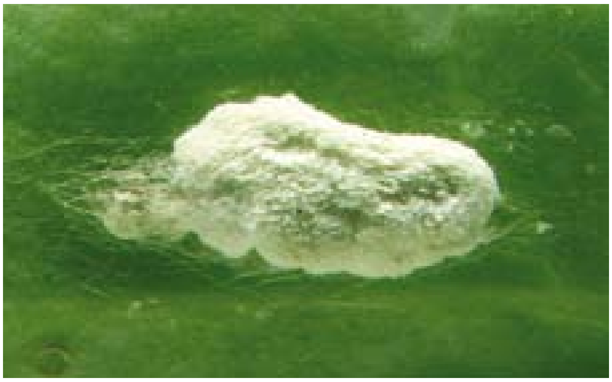


Figure 27. 'Mummy' of the entomopathogen *Beauveria bassiana*, on larva of diamond back moth, *Plutella xylostella.* (Photo: G. Goergen/IITA)

Crop damage

Extension workers and farmers often regard crop damage as equal to yield loss. Crop damage refers to harm or injury to the plant, but the injury may, or may not, lead to yield loss. Crop damage by pests can be direct or indirect.

- ***Direct damage*** – injury of plant parts that are harvested for consumption and/or sale, (e.g. leaves of leafy vegetables), which causes yield losses.
- ***Indirect damage*** – injury of plant parts that are not consumed or sold (e.g. leaves of root vegetables). The effect of indirect damage on yield loss is unpredictable and is often not as serious as that of direct damage. Depending on the type and age of crop and the timing of the pest attack, a defoliated plant can actually recover from damage by producing new or replacement leaves.

Yield loss

Yield loss is the partial or total loss of consumable or marketable plant parts of the crop. The loss can be in quantity or quality. In vegetables, quantity losses are easier to spot and appreciate than are quality losses. Quality losses are due to a reduction in the nutritional value or marketability of the produce. Quality losses tend to be overlooked under poor socio-economic conditions but are nonetheless very important in the vegetable trade. There is a wide range of quality factors which can lead to rejection of the produce by traders, especially on international markets:

- Blemished fruits
- Deformed and discoloured leaves
- Damaged storage roots
- Appearance of living and dead organisms (e.g. insects, mites)
- Appearance of quarantine pests
- Pesticide residues.

Pest abundance and yield loss

High levels of pest damage can often lead to total yield losses within the period between planting and harvest. Pest abundance and levels of crop damage may not always be an indicator of the level of yield loss to expect. This can result in poor pest management decisions. For certain pests, (e.g. leaf feeding pests of leafy vegetables), higher infestation leads to higher losses. In other cases (e.g. insect vectors of plant diseases), even light infestations can cause high yield losses. For certain other types of pests, high pest infestations, which can cause an alarming amount of defoliation on the plants, may not necessarily lead to high yield losses. The relationship between abundance of pests and yield loss is complex and depends on many factors which include the:

- Timing of pest attack
- Plant age and growth stage at the time of attack
- Developmental stage of the attacking organisms
- Growing conditions/agronomy of the crop
- Duration of pest, disease and weed infestation.

Economic threshold

There is usually a cut-off level of pest infestation or crop damage above which further damage is unacceptable, because experience shows that further damage will lead to significant yield loss. Damage is usually acceptable below this level, because experience shows that below that level, the plants can tolerate some damage, and the damage observed will not cause economic loss in yield. Controlling pests whose infestation or crop damage is below the level where they will cause economic damage is not necessary. In other words, a certain amount of pest damage of the crop cannot prevent the achievement of high yields. Farmers need to work out the pest density or crop damage level that can be tolerated as a guideline in their decisions about how to manage pests on their crop.

The term 'economic threshold' (ET) is used to refer to the pest population or damage level below which control measures are unnecessary. The economic threshold is also sometimes called the 'action threshold' as it represents the point at which a control action is started. The economic or action threshold is very dynamic and flexible and usually:

- Applies to use of pesticides to reduce pest abundance from high to low levels
- Does not apply to use of natural enemies which prevent pest abundance from increasing to high levels
- Does not apply to cultural practices which help to prevent or limit pest infestations from increasing to damaging levels
- Varies from pest to pest, and is high for pests that cause indirect damage, but low for those which cause direct damage
- Varies from farmer to farmer, even in the same neighbourhood and for the same crop variety, and depends on consumer standards. Farmers adopt more stringent pest management measures if they aim to sell their produce in markets for high income societies. Contamination of the produce by fragments and frass of pests can also dictate stringent pest management measures. These conditions will translate into low economic thresholds for the pest. On the other hand, higher economic thresholds prevail if farmers aim to sell their produce in markets where low income societies predominate. Low income customers are often market outlets for damaged goods, but the same poor quality produce would be rejected by high income societies with higher consumer standards. Generally therefore, economic thresholds decrease as the value of the crop increases; and economic thresholds are often high for subsistence farmers and low for commercial farmers
- Varies from location to location, since the agroecological conditions that affect populations differ between locations
- Varies from season to season, since temperature, rainfall and humidity conditions that affect populations differ between seasons.

Frass: Debris or excrement produced by insects.

The determination of the economic threshold is, therefore, complex and difficult and is mostly left to researchers to investigate. Farmers usually rely on their experience with previous infestations, and not ETs, to decide whether or not to treat current infestations. Extension workers should exercise caution in introducing the concept of economic threshold to farmers.

Pest monitoring

Vegetables are generally short duration crops. Cabbage, for example is harvested three months after transplanting while amaranth leaves are harvested three weeks after transplanting, if harvesting is by uprooting whole plants. When amaranth is harvested by ratooning, the first of successive harvests begins about 40 days after transplanting, followed by harvests at 10-day intervals. Most of the pest damage – sometimes equivalent to 100% crop loss – can occur within the short period between planting and harvest. Vegetable production therefore requires farmers to monitor their farms/plots regularly and assess changes in plant health, pest status and crop damage. Through frequent field inspections, farmers can identify pest problems in time and act quickly to prevent pests from spreading and causing further damage to crops. The chapter on field diagnoses advises extension workers and farmers on the key tasks, knowledge and skills essential for pest monitoring.

Farmers' coping strategies

Chemical control is a common coping strategy used by farmers to protect their investment in vegetables (Figure 28). However, the list of pesticides currently used against vegetable pests in West Africa includes products that are banned for use or are extremely toxic, according to the WHO classification of pesticides. Chemical pest control is so frequently used in vegetables that crops such as African eggplant, cabbage, pepper and tomato have become indicator crops of inappropriate pesticide regimes in many vegetable agroecosystems. Cabbage producers apply pesticides every 3 to 4 days within a 3-month period before harvesting, in order to control caterpillars on the crop. Farmers also apply 18 applications of pesticides on pepper within 10 weeks of crop growth to control aphids, mites and whiteflies; and 12 applications of pesticides on the African garden eggplant within 10 weeks of crop growth to control mites and root-knot nematodes.

Various field training programmes promote botanical pesticides as alternatives to chemical pesticides for many vegetable pests in West Africa. Leaf and seed extracts of the neem tree *Azadirachta indica* are the most popular botanical pesticides against foliage feeding pests. Farmers often self-supply the plants from wild areas or grow them in their neighbourhoods. Biopesticides have the potential to limit inappropriate pesticide use in the sub-region. In some countries, such as Ghana, farmers have been introduced to commercial formulations of biopesticides to control foliage feeding caterpillars on vegetables, but they are not commonly available in West African markets.

Under traditional farming conditions and on small vegetable plots, weeds are controlled by labour and time-intensive slashing and hand/hoe weeding. Agronomic practices such as close plant spacing and intercropping are also used to produce thick leaf canopies that act in the same way as cover crops by minimizing weed germination and growth. The use of herbicides in vegetable production is rare in many West African countries.

Figure 28. Pesticide application at a vegetable production site. (Photo: A. Staverløkk/ Bioforsk)

Integrated pest management

Integrated pest management (IPM) is the science of combining different options and practices to achieve long-lasting control of pests. The approach frequently blends technologies from research with traditional farming practices, to reduce crop losses in a sustainable manner. The success of IPM depends largely on farmers' knowledge and understanding of biological and ecological processes that affect pest status. The extent to which farmers use that knowledge in the choice of introduced options to blend with their farming practices also affects how well IPM works. Implementing IPM causes minimum damage to humans and the environment, and helps to increase the food and income value at harvest. Participatory research and learning approaches, facilitated by extension workers, help to increase farm-level literacy in IPM and promote utilization of IPM to solve pest problems. The rest of this guide is devoted to the need to provide agricultural extension workers with knowledge and skills required to plan and promote IPM in vegetable production. The key areas covered are:

- Field diagnosis to detect and monitor pests and natural enemies, assess crop damage severity, and develop vegetable pest lists
- Field and laboratory techniques to collect, preserve, and send pest and natural enemy specimens to experts for identification
- Pest facts sheets that assist extension workers and farmers to rapidly identify and understand pests
- IPM options including guidelines on appropriate use and handling of pesticides
- Experiential learning and dissemination of IPM.

Experiential learning is the process of learning from direct experience. It is 'learning-by-doing.'

Field diagnosis

Diagnostic surveys aim to gather and analyse information on vegetable production, plant protection, market practices, status, problems and opportunities. The surveys help agricultural extension workers to specify farmers' needs, identify key problems needing attention, and advise on the kinds of support required to address the problems encountered. Generally, diagnostic surveys cover extensive areas, diverse vegetable agroecosystems, and a large number and wide range of farmers. This allows researchers and extension workers to discover and describe problems and opportunities faced by farmers in different localities. Results of field diagnosis help to promote informed decision-making in the development and use of pest management options.

Survey tasks and skills

Table 3 lists the tasks and skills required for diagnostic surveys which usually involve:

- ***Community consultation:*** Participatory diagnostic surveys involve talking with and listening to farmers and other stakeholder groups, and discussing and analysing emerging issues with them. At most vegetable production sites, there

Table 3. Tasks and skills in field diagnoses.

Tasks	Skills required
• Specify relative importance of vegetable crops. • Detect pests, develop and update pest lists. • Detect new, introduced and quarantine pests. • Identify pests of economic importance. • Identify and collect natural enemies. • Note changes in pest and natural enemy populations. • Estimate crop damage severity. • Note plant protection practices by farmers. • Note effects of pest management practices.	• Appropriate sampling and survey techniques. • Pests and natural enemy collection and identification. • Spotting life cycle stages of organisms. • Linking crop damage to specific pests. • Linking pest density to potential yield loss. • Experience in combining various options in an IPM system to achieve long-term control. • Spotting harmful effects of pest management practices on crops, environment and people.

are usually a number of farmers, each cultivating more than one vegetable crop on small plots. The farmers often share similar vegetable production problems and lack appropriate pest management information. Where the farmers work in organized groups, extension workers and representatives of these groups can work with researchers to jointly conduct diagnostic surveys. The participatory approach enables extension workers and researchers to focus their attention on farmers' felt needs.

- ***Field inspections:*** Sampling crops and pests, collecting specimens for identification.
- ***Reporting:*** Developing and/or updating information on lists of pests and their associated natural enemies, economic status of pests, and distribution maps of pests.

In participatory diagnostic surveys, survey teams should ideally be split into two sub-teams. One sub-team conducts community consultation with farmers' groups (Figure 29), while the other sub-team with a farmer representative inspects vegetable plots to specify field problems and opportunities faced by farmers at the locality. It is advisable to inspect fields at same sites once in the dry season and once in the rainy season. Dry season conditions, coupled with poor irrigation of vegetable plots can promote a rapid increase in the abundance of certain pests, and thereby aggravate the damage caused by these pests. Wet season conditions, on the other hand, may result in expression of damage symptoms caused by certain plant pathogens.

Figure 29. Key informant farmer interview. (Photo: B. James/IITA)

Focus group interviews

Focus group interviews provide a forum to discuss and agree on various issues, such as plant production practices, pest problems, plant protection practices, marketing, and other socioeconomic issues at the localities visited. The survey team uses a questionnaire which would have been pre-tested in the field prior to its use, to guide the discussions.

Questionnaire design

In designing the questionnaire, it is advisable to group questions that address common issues together under specific sub-sections. The questionnaire should start with a sub-section containing 'soft' questions to help relax the atmosphere and the interviewees. Questions relating to financial matters and other personal issues are best covered in the last sub-sections of the questionnaire. The questionnaire can contain 'factual' questions to which respondents can state if they 'agree', 'disagree', 'don't know' or 'neither agree nor disagree'. Similarly, factual questions can relate to practices for which the survey team would like to assess respondents' awareness (either they have heard, or not heard, about the issues raised), level of understanding (good, average, or weak/poor), and adoption (percentage of respondents who say they have adopted the practice).

The questionnaire should be of reasonable length so as to retain the interest of respondents, who will certainly have other things to do on the day of the interview. The questionnaire needs to be in a format that allows for quick and easy data entry and analyses. The contents of a focus group interview questionnaire can be organized into five main parts:

1. *Overview:*
   - Total number of respondents (indicate women and men) in the focus group
   - Membership of respondents in farmers' groups or associations
   - Position of focus group members in farmers' groups or associations
   - Number of respondents (indicate women and men) who grow vegetables at the site
   - List of the most important vegetables grown by the respondents
   - Vegetable production seasons in the locality, e.g. year round; dry season only; wet season only (specify which important vegetables are grown in which season).

2. *Plant production practices:*
   - Area under vegetables (specify crop)
   - Size of vegetable bed
   - Number of vegetable beds per crop per farmer
   - Number of vegetable plants per bed per vegetable –in sole crops (note plant spacing during field inspection)
   - Seed germination test (probe farmers to describe methods used, if any)
   - Fertilizer used (inorganic or organic fertilizer, crop treated, type and name of

fertilizer used on the crop, source of the fertilizer, quantity/volume, method and frequency of application of the fertilizer
- Weeding (probe farmers to describe method and frequency).

3. *Plant protection practices:*
   - Knowledge of pests/diseases
   - Ability to identify and link pests/diseases to their respective damage symptoms
   - Knowledge of natural enemies
   - Ability to identify and link natural enemies to particular pests
   - Plant protection products used, e.g. chemical pesticides, biopesticides, botanicals (probe farmers to specify crop treated, type, source, quantity/volume, method and frequency of application of the plant protection product)
   - Factors that influence the choice of plant protection products, e.g. cost, availability, efficacy, safety, advice from extension staff or other farmers or dealers of plant protection products
   - Knowledge of the side effects of plant protection products (probe to learn farmers' knowledge, awareness and perceptions of the effects of plant protection products that they use against pests)
   - Nature of crop damage caused by plant protection products
   - Storage methods used for chemical pesticides, biopesticides or botanical pesticides (probe farmers to specify the place and method of storage; e.g. at home, on the farm, in special stores)
   - Use of empty pesticide containers (probe to find out the disposal method used, e.g. bury in a hole; use at home).

4. *Public awareness:*
   - Previous training e.g. number of respondents (indicate women and men), who were previously trained in vegetable production and plant protection
   - Knowledge of alternatives to chemical pesticides
   - Sources of information on alternatives to chemical pesticides (e.g. training, other farmers, extension, researchers, dealers of agrochemicals, radio/TV, etc.)
   - Source of information on seeds, organic fertilizers, inorganic fertilizers, chemical pesticides, biopesticides and botanical pesticides (e.g. training, other farmers, extension/researchers, dealers of agrochemicals, radio/TV, etc.).

5. *Costs and benefits of production:*
   - Source of funds for growing the crop (name the crop – probe to discover if funds were obtained through self-financing, borrowing, grants, etc.)
   - Market outlets for farmers who sell vegetable produce (probe to learn who buys directly from the farmers e.g. traders, local markets, international markets, hotels, restaurants etc.)
   - Cost of production and benefits from sales – see Appendices 1 and 2 for calculation of costs and benefits – encourage the group to estimate the lowest and highest costs or price for each line item. Farmers may cost and price estimates in terms of traditional units such as 'price per bed of vegetables', 'price per sack load of vegetables', 'price basket load of vegetables', which the survey

team can later convert to standard units (income per hectare)
- Income per year from all vegetables (encourage the group to state the lowest and highest income per year from their vegetable farms)
- Annual household income from other enterprises (encourage the group to state the lowest and highest income; the survey team can later work out the percentage of total household income that comes from the sale of vegetables).

Questionnaire delivery

Focus group interviews are ideally conducted by a team of three (team leader, recorder and translator). The team leader should be a good communicator with experience in community consultation skills. At each site, the team member uses a GPS receptor (Figure 30) to record the longitude, latitude and altitude of the location visited. In the delivery of the questionnaire, the team leader should explain each sub-section to the respondents, so as to promote group understanding of the relevance of questions that will be raised for discussion. For any question raised for discussion, there will be diverse responses from focus group members. The survey team should therefore encourage respondents to explain their responses clearly. The second team member (a recorder), as well as other team members, should listen attentively, especially to identify areas where the focus group members are unsure of their responses. During the discussions, the recorder records farmers' responses. Additionally, the recorder would need a notebook to enter other observations and relevant remarks. Instructions to the recorder should be clear and unambiguous, so that s/he records what is agreed upon on the questionnaire sheets. The third member of the team, ideally a field agent based in the locality, assists with local language translations. Appendices 1 and 2 summarize results from a focus group interview with a vegetables farmers' group in a peri-urban area of Benin.

Figure 30. A GPS receptor. (Photo: C. Atcha-Ahowé/IITA)

Field inspections

Many different kinds of pests, natural enemies and plant production practices occur in vegetable agroecosytems. Some of the pests have a wide host crop range whilst others have a narrow host crop range. Some of the pests are native pests i.e. they have always been in the region, whilst others are introduced pests. In the absence of effective natural enemies, introduced pests adapt, multiply and spread widely in new regions. Introduced pests that spread rapidly in new regions are often called 'alien invasive species'. Field inspection enables survey teams to specify these and other features of vegetable plant production in the farmers' fields.

Introduced pests are those that have been imported (accidentally) into a new region without their associated natural enemies.

Whilst the focus group interview is being conducted, a second survey team comprising plant production expert(s) and plant protection expert(s) inspect(s) the vegetable plots/farms with the farmer (or his or her representative) (Figures 31 and 32). The experts and the farmer jointly gather information on priority crops, pests, crop damage, natural enemies, plant production and plant protection practices on the farm. In order to have a representative summary of the field situation at the survey site three to five different farmers' plots per crop at the locality of the focus group interview should be inspected. Table 4 summarizes activities suggested for each farm/plot. The next chapter covers specimen collection techniques.

Figure 31. Inspecting vegetable plants for pest damage. (Photo: C. Atcha-Ahowé/IITA)

Figure 32. Technician (left) with vegetable farmer (right) viewing mites under a microscope. (Photo: B. James/IITA)

Table 4. Field inspection tasks during diagnostic surveys.

On each farm visited	On each vegetable bed selected	
	Assess pest incidence	Assess damage severity
Record number of beds (indicate bed size) with sole crop vegetables and name the sole crop. Record number of beds with intercrops and name the intercrops. Indicate the predominant crop in the intercrop. Choose three vegetable beds per crop.	Randomly select and tag 5 vegetable plants of the target crop per bed (exclude guard row plants). Inspect leaves, stems, flowers, fruits and roots of each tagged plant to identify and collect pest, diseased plant parts and natural enemy specimens (except nematodes). Refer to sampling techniques for nematodes.	Assess damage severity on each tagged plant by specifying level of damage symptoms on marketable part of the plant. Rate damage severity as: Low = less than 10% of the plant organs are damaged. Moderate = 10 to 30% of the plant organs are damaged. Severe = more than 30% of the plant organs are damaged.

Economic status of pests

Crop damage severity data are used to categorize pests as minor or key.

The 10% cut-off point is based on a combination of factors. The consumable and marketable parts of the crops are vegetable leaves, fruits, and in some cases, roots. Depending on the crop, pest damage to these plant parts is equivalent to direct food and economic loss. The level of damage that can be tolerated is therefore low. Another factor that guides the decision on the 10% cut-off point is that most vegetables have short life cycles (3 weeks to 3 months, depending on the crop) and do not regrow damaged foliage parts prior to harvest. In order to ensure that the damage does not become severe, farmers must act quickly. Again, this means that stringent measures are required to prevent big losses. Generally, the value of 'economic thresholds' for vegetable pests is inherently low.

Minor pests can become economically important when the natural processes and farming practices that prevented them from causing severe damage are disrupted. This can happen in many ways, such as through:

- The introduction of new crop varieties that are favoured by minor pests
- Inappropriate pesticide applications which kill off natural enemies of pests and enable their populations to increase rapidly
- Weak phytosanitary measures which promote rapid spread of pests
- Climate change and variability (e.g. abnormal fluctuations in temperatures, relative humidity and wind currents) which can increase the number of generations produced by pests and reduce the ability of crop varieties, natural enemies and pesticides to control pests.

If more than 10% of the entire number of vegetable plants inspected show moderate to severe damage, then the pest causing the damage can be regarded as an economically important pest, and the pest is classified as a **key pest**.

If less than 10% of the entire number of vegetable plants inspected show moderate to severe damage, then the pest causing the damage can be regarded as an economically unimportant pest, and the pest is classified as a **minor pest**.

Pest lists

Diagnostic survey data are used to develop and/or update a list of pests found on crops in any particular locality and time. Pest lists (see Appendices 3 to 8) provide baseline information which:

- Informs the public on the range of pest problems to expect in a locality
- Helps decision-making by farmers and extension workers about pests that need immediate attention
- Assists research planning on the kinds of pest problems which might benefit from further research
- Guides trade in vegetables. Comprehensive pest lists provide information on the kinds of pest species that are likely to enter a country along with its imported vegetables. If quarantine pests enter a new country, favourable climate and occurrence of suitable hosts can enable that pest to establish itself and threaten the economy of that country. Vegetable pest lists are therefore of particular importance to countries which produce and export vegetables and to those which import vegetables.

Pests that are not allowed to enter a country from another country are referred to as **quarantine** pests.

Techniques for collecting specimens

To develop pest lists, extension workers must be fully familiar with the identification, biology and life history of pests and their associated natural enemies. Extension workers also need to have skills in collecting insects, mites, pathogens, plant parasitic nematodes, natural enemies and other organisms. Agricultural research institutes and plant protection organizations use reference collections to help in identifying specimens of insects, mites, nematodes, pathogens and natural enemies that they receive from extension workers' agents.

Different methods and equipment are used to collect specimens of organisms from plants. On vegetables, the factors that determine which method and equipment to use include size, shape, developmental stage and behaviour of the organisms and the plant parts attacked. Tiny insects, mites, pathogens and plant parasitic nematodes are usually collected by handpicking them off the affected plant parts. For many insects, caterpillars/larvae are the developmental stages most commonly found on vegetables. Correct identification of many of these insects normally requires adult insects. Larvae collected in the field should therefore be reared to adults in order to confirm the identity of the insects.

Over time, the collection of specimens by extension agents grows into an inventory of organisms found on the crops in a country. This inventory is known as a **reference collection**.

Insects and mites

Three methods are most appropriate for collecting insects and mites from vegetables. These are handpicking, use of aspirators (also known as 'pooters') and aerial nets (Table 5). Handpicking is the simplest method for collecting specimens that are large in size and/or relatively docile. Handpicking is also used for collecting plant parts from which tiny insects and mites can be removed with a camel hair brush or an aspirator. The equipment frequently used to collect insects and mites are:

- *Killing jars:* These are wide mouth glass jars with cotton wool or plaster of Paris placed at the bottom and soaked with ethyl acetate.
- *Rearing jars:* These are wide mouth jars with the mouth covered with fine cotton mesh to allow ventilation for live collections.
- *Rearing boxes:* These are perforated boxes to allow ventilation for live collections.
- *Aspirators:* These are used to collect large numbers of tiny insects that would otherwise escape or be damaged if they were handpicked.
- *Aerial nets:* These are light and used to collect flying insects.

Other items include a camel hair brush, vials with 70% alcohol, brown paper bags or envelopes, covered petri dishes with blotting paper. Other insect collecting equipments include sweep nets and beating sheets but these are not suitable for use on vegetables. Sweep nets are built of heavy and hard-wearing material. The nets are swung across a plant's surface to capture insects into the net. Beating sheets are useful for collecting insects and mites (especially sessile and wingless specimens) that sit on larger plants and are mostly hidden from view. In the use of beating sheets the vegetation is beaten with a stick, forcing the insects to fall on a sheet placed below the plants. Specimens on beating sheets or sweep nets can be handpicked or sucked into an aspirator. The use of sweep nets or beating sheets easily damages crops and they are therefore unsuitable for use on vegetables.

Table 5. Insect and mite collection techniques.

Organism	Equipment	Collecting	Handling
Large size insects	Forceps Killing jars Vials with 70% alcohol	If the insects are likely to bite or sting, use forceps to pick them up from the plant; otherwise pick them up with the fingers. Kill and preserve adult insects by transferring them in killing jars or into vials with alcohol. Put adult butterflies/moths into killing jars and not into alcohol.	Transfer dead and dry specimens from killing jars into envelopes or dry vials. Retain wet specimens in vials with 70% alcohol. However, insects may lose their original colour in alcohol (do not put butterflies and moths in alcohol). Therefore, insects collected in alcohol should be sent to laboratories quickly. Label each collection appropriately and send the labelled collections to experts for identification.
Insect larvae (caterpillars, grubs, maggots and nymphs) and mummies on leaves, stems and roots	Paper bags or envelopes Rearing boxes Rearing jars Vials with 70% alcohol	Hand-pick plant parts to collect organisms found on them. Put infested plant parts or mummies into paper bags or rearing boxes/jars. Collect some of the insect larvae into vials with alcohol. Do not put mummies into alcohol.	Seal and keep each paper bag or rearing table or rearing jar undisturbed at room temperature until adults emerge. Retain wet specimens in alcohol. Keep mummies dry until they hatch out into parasitoids. Label and send the collections to experts for identification.
Insect larvae (caterpillars, grubs, maggots) in flowers, flower buds and fruits	Rearing jars Vials with 70% alcohol	Place flowers, flower buds and fruits into the rearing jar. Open up the flowers, flower buds and fruits to collect insect larvae and place them into vials with 70% alcohol.	Keep the rearing jar with the plant parts undisturbed at room temperature until the adults emerge. Transfer dry specimens of adults into envelopes or dry vials. Retain the wet specimens in alcohol. Label and send collections to experts for identification.
Nymphs and adults of tiny insects (e.g. parasitoids)	Aspirators Vials with 70% alcohol Killing jars Rearing jars	Suck tiny insects from foliage or aerial nets into the aspirator. Transfer the specimens into killing jars or vials with 70% alcohol.	Transfer dry adult specimens from killing jars into envelopes or dry vials. Retain wet specimens in vials with 70% alcohol. Label and send collections to experts for identification.

Table 5 continued

Organism	Equipment	Collecting	Handling
Flying insects, e.g. butterflies, moths, flies, wasps etc.	Aerial nets Killing jars Aspirators Vials with 70% alcohol	Swing open end of net back and forth in the air to collect flying insects. Transfer specimens from the net into a killing jar using an aspirator. Hand-pick large specimens from the net. Transfer specimens into killing jars or vials with 70% alcohol.	Transfer dry specimens of adults from killing jars into envelopes or dry vials. Retain wet specimens in vials with 70% alcohol. Label and send the collections to experts for identification.
Mites on leaves	Vials with 70% alcohol Covered petri dishes Blotting paper Camel hair brush	Collect leaves with the specimens. Brush the specimens from the leaves into vials with 70% alcohol. Keep some of the mites alive by placing mite infested leaves on moist blotting paper in covered petri dishes.	Retain wet specimens in 70% alcohol. Inspect live specimens for preliminary identification. Label and send collections to experts for identification.

Plant pathogens

Each group of plant pathogens causes unique disease symptoms on the plant. Plant pathogens are usually identified by the particular damage symptoms displayed by the plant. Table 6 summarizes the damage symptoms caused by different groups of plant pathogens and techniques for collecting the pathogens. Note that other organisms can cause damage symptoms similar to those caused by plant pathogens. It is therefore always advisable to collect and send diseased plant parts to laboratories for analyses. Researchers extract pathogens from the damaged plant parts (Figure 33) and test them on healthy plants to see if the pathogens extracted will cause the same kinds of symptoms observed in the field (Figure 34). In this way, researchers advise extension workers and farmers on the true identity of plant pathogens collected from crops.

Microbial organisms commonly found in vegetable fields are bacteria, fungi and viruses. Certain kinds of microbes (called **plant pathogens**) infect, cause diseases and kill vegetable plants. Other kinds of microbes (called **entomopathogens**) infect, cause diseases and kill insects, mites and other pests.

Figure 33. Diseased lettuce leaves. (Photo: F. Beed/IITA)

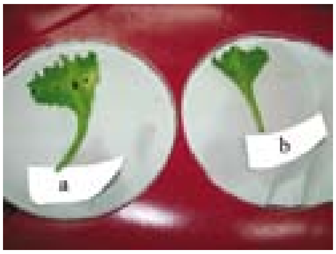


Figure 34. Diseased (left) and non-diseased (right) lettuce leaves. (Photo: F. Beed/IITA)

Table 6. Damage symptoms caused by plant pathogens and techniques for their collection.

<table>
<tr><th>Pathogen</th><th>Plant damage symptoms</th><th>Collection technique</th></tr>
<tr><td>Bacteria</td><td>Leaf spots
Leaf blight
Plant defoliation
Stem dieback
Rotting of plant parts
Cankers/scabs

Quick test:
Cut stem and place in clean jar of water; a stream of cloudy milky paste into the water indicates the presence of bacterial disease.</td><td rowspan="3">If damage symptoms are observed on leaves, stems or fruits:
Use sharp and clean tools e.g. knives, to collect fresh materials in the field. Do not collect samples from dead or dry plants.

Collect several plants or plant organs that show clear disease symptoms.

Put samples in paper bags or sampling bags; keep them in cool boxes if possible. Leaf samples can be placed in between pages of newspapers.

Label each collection of diseased leaves, stems or fruits indicating same details as per insect or mite collections.

Send collections quickly to the nearest laboratory. Do not keep specimens for long periods because plant parts rot, dry out and deteriorate quickly.

If root or stem collar is infected:
Uproot the whole plant with the roots intact and with some soil on it.

Wrap the plant in a dry paper bag then put the paper bag into a plastic bag (i.e. ‘double bag’ the sample).

Seal and clean the plastic bag by removing plant debris and soil particles.

Label each collection and send collections quickly to the nearest laboratory.</td></tr>
<tr><td>Fungi</td><td>Leaf spots
Patches of localized dead tissue (necrotic lesions) on the surfaces of leaves, stems and roots
‘Shot-hole’ appearance of leaves when necrotic lesions fall off
Blighting, i.e. death of foliage without rotting or withering of foliage
Sudden cessation of plant growth
Wilting of plants (i.e. the leaves droop as if suffering from drought)
Mildew, i.e. visible whitish growth that covers the surface of the plant leaves
Damping-off (in seedlings)
Stem die back
Stem rot
Root rot</td></tr>
<tr><td>Viruses</td><td>Abnormal appearance of the foliage
Distorted leaf shape
Abnormal plant growth, smaller less vigorous plants
Chlorotic patches on leaves
Leaf variegation[1] (which can also be caused by other factors)
Mottled, misshapen or necrotic fruits
Stunted plant growth</td></tr>
</table>

1 Less cholorphyll in some parts of the leaves resulting in a paler or mottled effect

Entomopathogens

Common entomopathogens are bacteria, fungi, viruses and to a lesser extent, nematodes and protozoa. As with plant pathogens, each group of entomopathogens causes unique disease symptoms, which usually appear on external surfaces of diseased or dead insects or mites. The dead specimens are referred to as cadavers. Good knowledge of disease symptoms of cadavers caused by different entomopathogens is therefore important in making field collections of these natural enemies. Table 7 summarizes the appearance of disease symptoms caused by different groups of entomopathogens.

Table 7. Disease symptoms caused by common groups of entomopathogens.

Entomopathogen	Disease symptoms in infected insects or mites
Bacteria	Cadavers are dark in colour and shrivelled up.
	Fresh cadavers are soft and flaccid.
	The body surface of the cadaver is unbroken.
	The body of the cadaver does not turn into liquid.
Fungi	The body of the infected insect or mite quickly dries up into a cadaver (known as a mummy).
	The cadaver remains dried up and not flaccid.
	If the host was soft-bodied (e.g. insect larvae or mites), the mummy will be covered with fungal mycelia and spores (Figures 27 and 35).
	If the insect was hard-bodied (e.g. adults of weevils), the fungus breaks out through the soft parts of the body in between body segments of the mummy.
Viruses	Normally smaller than healthy larvae (Figure 36)
	Pale in colour and flaccid prior to death
	Dark in colour after death
	Usually hang on plant parts where they die and the cadavers are found on the top branches of plants
	The body of the cadaver turns into liquid

Bacteria: Bacteria are tiny and can not be seen with the naked eye. Certain bacteria are plant pathogens whilst others are entomopathogens. Entomopathogenic bacteria attack insect larvae and insects which feed by chewing the foliage and fruits of plants or insect larvae. They do not normally infect insects which feed by piercing and sucking sap from plant tissues. When an insect ingests the bacteria, the pathogens invade, reproduce and release toxins into the body fluids of the insect. The infected insects stop feeding and die.

Fungi: Fungi reproduce by spores which grow into strands known as mycelia. The spores germinate, invade insects and mites, and use water and nutrients in the infected organism to grow. The fungus grows, multiplies and spreads rapidly inside the organism. Extensive growth of the fungus (Figure 35) coupled with accumulation of toxins it secretes, kills the organism. In dry environments, the symptoms listed (see Table 7) may not appear, but spores and mycelia remain embedded inside the cadaver.

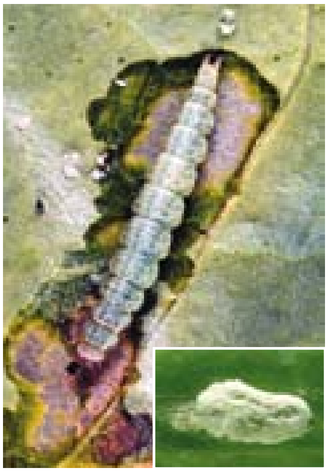


Figure 35. Larva of diamond back moth and 'mummy' of the entomopathogous fungus *Beauveria bassiana* with white mycelia of the fungus (inset). (Photo: G. Goergen/IITA)

Viruses: Viruses can only be viewed using powerful microscopes. They consist of strands or particles of genetic material (known as virions) which may be

Figure 36. Normal size of diamond back moth caterpillars (upper) and size of the caterpillars of the same age killed by virus disease (lower). (Photo: G. Goergen/IITA)

covered by a protein coat called an occlusion body. These kinds of viruses are known as occluded viruses. In non-occluded viruses, the genetic material is not covered by a protein coat. Viruses cannot grow outside living tissues and cannot move or metabolise food on their own. In other words they are obligate pathogens, meaning they can only live and survive inside living tissues (Figure 36). Certain viruses are plant pathogens whilst others are entomopathogens. Larvae of insects are the most commonly attacked by entomopathogenic viruses. When an insect feeds on a leaf, fruit, stem or other plant part that is contaminated with entomopathogenic viruses, the occlusion body (protein coat, if present) of the virus dissolves in the gut and releases virions into the insect's body. The virions invade the body and quickly join up to form new viruses in different organs of the insect's body, resulting in the death of the insect.

Nematodes: Plant parasitic nematodes are economically important pests of vegetables feeding on the roots and foliar parts of plants. Entomopathogenic nematodes are not parasitic on plants, but infect insects, and can be used as biological control agents in pest management. The colour of insects killed by nematodes often changes.

Protozoa: Protozoa can only be seen under microscopes. When an insect ingests spores of a protozoan, the pathogen grows and penetrates the insect's gut causing chronic diseases. Protozoa kill the insect only if relatively high numbers of the pathogen infect the insect. Symptoms of protozoan diseases are difficult to identify in the field.

The most frequently used entomopathogens in vegetable pest management are bacteria, fungi and viruses. Box 3 summarizes the techniques for collecting entomopathogens.

Plant parasitic nematodes

Certain **plant parasitic nematodes (PPN)** move from the soil to feed on the plant foliage and are called aerial nematodes.

Plant parasitic nematodes (PPN) are probably the most common soil-borne pests of vegetables in West Africa. They feed on plant roots and sometimes on the foliar parts of plants. Comprehensive and accurate data on the identity, diversity, and distribution of PPN on vegetables are not readily available in most countries owing to a shortage of trained specialists in the region. Extension workers can send samples of soils and roots to laboratories and specialists for PPN identification. The information provided from scientists can indicate the host crop range of nematode pests. This helps farmers to decide on suitable rotation crops and intercrops for effective management of these pests.

Box 3: Techniques for collecting entomopathogens

Look for cadavers

Collect insect pathogens by searching for cadavers on leaves, stems, flowers and fruits of vegetables and wild plants in and around the field. Cadavers of larvae killed by viruses are usually found hanging on the top branches of plants. Note the disease symptoms and put dead specimens singly in sterile glass or plastic vials with screw caps, or in paper bags or in envelopes. Do not put dead insects suspected of being killed by viruses in paper envelopes as the cadaver liquifies and the liquid will be absorbed by the paper. Keep the collections at room temperature in a clean dry room or send them to a laboratory. To dry the specimens, open each vial or envelope and leave each one open for three to four days. This will allow the specimens to dry out naturally and remain in good condition for several days. Do not dry the specimens in the sun or by any artificial means. Store the air-dried specimens in screw cap vials or envelopes. Alternatively, store air-dried specimens in a refrigerator (at a maximum temperature of 5°C), if a refrigerator is available. Do not store the specimens in alcohol. Label each collection of air-dried specimens with the same details provided for insect and plant pathogen collections. Send the air-dried specimens to experts who will examine and identify the insect pathogens. Pack the specimens in crush-proof paper envelopes. Plastic materials are not good for packaging the specimens because condensation in plastic bags can contaminate the specimens. Label each package 'biological specimens for scientific study'.

Look for live insects or mites

Ants and birds may rapidly remove cadavers in the field, hence cadavers may not be found in the field during the survey. A small proportion of live insects or mites may however be infected by entomopathogens. Collect live specimens for examination in the laboratory. Collect and feed live specimens of the insect or mite on their preferred plant in cages or on preferred plant parts in small ventilated insect rearing boxes. Rear many individuals of the insect or mite on their preferred host plant or plant parts. Stress caused by overcrowding and high humidity in the cages will promote the appearance of diseases. Water the plants regularly to maintain high humidity in the cage or replace the plant parts in the rearing boxes each day. Observe the organisms for signs of abnormalities, especially in their feeding and movement, and for signs of disease. It can take up to three weeks for disease symptoms to appear, depending on the insect or mite, type of pathogen, and the conditions under which the specimens are reared. Watch out for insects which tend to hide or climb up the plant on which they are being fed. They may be diseased. Leave diseased specimens on the plant to develop and dry into cadavers. Collect cadavers and place in sterile glass vials and store in a refrigerator (at about 5°C). Label and send the air-dried specimens to experts who will examine and identify the insect pathogens.

Figure 37. Galls caused by root-knot nematode damage to vegetable roots. (Photo: B. James/IITA)

Figure 38. Reduced root mass caused by root-knot nematode damage to vegetable seedling. (Photo: G. Goergen/IITA)

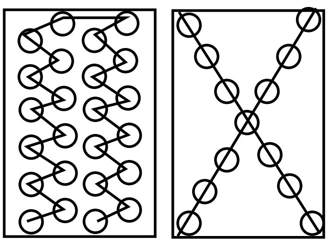


Figure 39. Patterns showing locations for sample collection in systematic sampling.

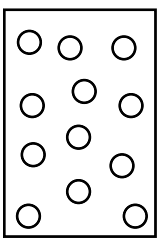


Figure 40. Pattern showing locations for sample collection in random sampling.

Plant parasitic nematodes cause certain plant damage symptoms on the roots, stems and leaves of vegetables:

- Galls on roots (Figure 37), shortened and deformed roots, blackened and necrotic roots, reduced root mass (Figure 38), lesions on the roots, cracking of root surfaces
- Chlorosis or yellowing of leaves, stunted plant growth, patchy distribution of plants in the field, thin leaves, leaf wilting or leaf rolling
- The damage caused by aerial nematodes can appear as galls or abnormal swelling of the seeds or leaves, striped leaves, chlorosis/discoloration of leaves, and death of flowers.

Crop damage caused by PPN is often non-specific. Soil and affected plant parts should be examined in order to verify the presence and identity of nematodes. Special techniques required are nematode sampling, extraction, and preservation.

Sampling for nematodes

Plant parasitic nematodes usually occur in high density clusters in the soil which appears as areas of poor, stunted or chlorotic plant growth in the field. Collection of root and soil samples is necessary to determine the presence of PPN and establish if they are causing the problem. A systematic sampling method (Figure 39) provides more reliable results than random sampling (Figure 40), for large areas.

For large plots:

- Divide the field into 1 ha plots.
- For each 1 ha plot, select and tag vegetable plants at sampling points in a systematic pattern. The distance between sampling points should be between 5 m and 10 m.
- Collect 10 to 50 root samples complete with surrounding soil from plants at sampling points.
- If the crop has not yet been planted in the field, collect soil samples at sampling points. This will establish the initial level of nematode infestation before planting of the vegetables.

For small plots:

In some areas vegetables are cultivated on small plots subdivided into ‘beds’. On these small-sized beds, random sampling (Figure 40) can provide a representative collection of nematode species in the roots and soil. For such small plots:

- Choose three vegetables beds (indicate bed size) per crop.
- On each bed, select and tag five vegetable plants (excluding guard row plants). The distance between sampling points can be between 0.1 m and 1 m, depending on the bed size.
- Collect root samples randomly from the five plants and do not collect samples from dead plants.
- If the crop is not yet in the field, collect soil samples at five random locations per bed in order to determine the initial level of nematode infestation before planting vegetables.

To collect a root and soil sample:

Step 1: Use a hand trowel or the flat edge of a machete or broad knife to uproot the plant (Figure 41). Uproot the plant with the entire root system and surrounding soil intact. Do not collect samples of dead plants.

Take soil samples at a depth of 20 cm to 30 cm

Step 2: Put the root sample with attached soil in a plastic sampling bag. Cut the root system from the plants at the base of the stems (Figure 42). Place all or a good selection of the roots collected in each 1 ha plot (large farms) or in each bed (small plots) into a single plastic bag. Do not use paper bags because the bags become moist and tear easily and roots and soil will dry up quickly inside them.

Mix all soil samples into a single composite sample (1 kg) and place in a plastic sampling bag.

Step 3: Write a label in pencil on a piece of paper and tied it at the top of the bag (Figure 43). Alternatively, use a permanent marker to label the outside of the plastic bag. The label should have the following information:

- Name of the country where the sample was collected
- Name of locality where the sample was collected
- Date the sample was collected
- Host plant and plant part on which the sample was collected

Figure 41. Step 1 in soil sampling. (Photo: B. James/IITA)

Figure 42. Step 2 in soil sampling. (Photo: B. James/IITA)

Figure 43. Step 3 in soil sampling. (Photo: B. James/IITA)

1 kg is the recommended weight of sampling bags. Bags heavier than that would be difficult to carry.

- Name of crop and variety sampled
- Name of intercrops on the plot sampled
- Name of previous crop on the plot sampled
- Name of the person who collected the sample.

Seal the plastic bags and store them temporarily in a cool place, e.g. in the shade of trees. Do not leave the sample in direct sunlight because nematodes die easily in the sun. Put the samples in a coolbox and send them to the laboratory immediately after collection. Nematode survival decreases with time, therefore do not leave the samples for long periods before sending them to the laboratory.

Extracting nematode specimens from root and soil samples

The Baermann tray technique is the recommended method for extraction of PPN specimens from vegetable roots or soil samples. The steps for extracting nematodes from roots and soils using this technique are explained below. The technique relies on simple materials that are readily available. The technique is unsuitable for extraction of inactive stages of nematodes or large nematodes that are slow moving. Other techniques used to extract PPN specimens from vegetable roots or soil samples include:

- Cobb's decanting and sieving method – for extracting immobile and sluggish nematodes
- 'Sieving–centrifugation–floatation' method – for extracting fast moving/active, sluggish, small and large nematodes specimens. However, the method relies on relatively expensive equipment and expertise which are not available at most research institutes.
- Seinhorst cyst-elutriator technique – for extracting females of cyst nematodes which cannot go through sieves.

Box 4. Baermann tray technique for extracting nematodes from root and soil samples

Root samples

Shake off the soil from the roots and keep the soil separately in the plastic bag. Close the plastic bag. Wash the roots with water to remove all soil particles. Use tissue paper to dry up excess water from the roots. Put all the root samples collected per 1 ha (large farms) or per bed (small plots) together in a small plastic bowl. Cut the roots of each plant into small pieces. Each piece should be between 0.3 cm and 0.5 cm in length. Mix the pieces of roots from each large farm together in the bowl, and repeat for roots from small plots. For each group of roots, take a sub-sample of about 10 g to 20 g of the root pieces (the weight depends on the size of the roots and on the size of the sieve to be used).

Soil samples

Put the composite soil samples collected in each ha (large farms) or in each bed (small plots) into a single plastic bowl and mix each one thoroughly.

Take a sub-sample of 10 g to 50 g of soil (depending on the size of the sieve to be used).

Step 1: Place tissue paper in a plastic sieve with a large mesh size (Figure 44). Use a 3-ply tissue i.e. a Kleenex tissue (not a cotton handkerchief). Do not use toilet tissue paper because the pores in tissue paper are too big and will allow materials to leak out of it too quickly.

Step 2: Place the sieve into a plastic bowl and place the sub-sample of roots or soil on the tissue paper. Ensure that the root pieces or soil particles are evenly spread and do not lie on top of each other (Figure 45).

Gently pour water in between the sieve and the bowl until the water just dampens the root or soil sample (Figure 46).

Step 3: Leave the set-up undisturbed at room temperature for 2 to 3 days. During this period, the nematodes will move through the tissue paper into the water in the bowl (Figure 47).

Remove the sieve containing the root or soil sample on the tissue paper.

Pour the water (now containing the nematodes) from the bowl into a clean plastic cup. Leave it undisturbed for at least 2 hours. The nematodes will move to the bottom of the cup during this time period.

Step 4: Drain the water (supernatant) from the plastic cup until there is less than 50 ml of the water at the bottom of the cup. This liquid at the bottom of the cup is the suspension of nematodes. Put the suspension of nematodes in a screw cap vial and add hot water with a small amount of formalin to kill the nematodes.

Step 5: Label the vial correctly and send to experts for identification and counting of nematode species.

Figure 44. Nematode extraction from roots, step 1.

Figure 44b. Nematode extraction from soil, step 1.

Figure 45. Nematode extraction from roots, step 2.

Figure 45b. Nematode extraction from soil, step 2.

Figure 46. Nematode extraction from roots, step 3.

Figure 46b. Nematode extraction from soil, step 3.

Figure 47. Nematode extraction from roots, step 4.

Figure 47b. Nematode extraction from soil, step 4.

(Photos: B. James/IITA)

Box 4 – *continued overleaf*

Pest fact sheets

Many different kinds of pests (insects, mites, pathogens and plant-parasitic nematodes) attack and feed on vegetables. Extension workers must be able to correctly identify these pests in order to advise on appropriate control measures and to share their knowledge and experiences with other people. In West Africa, agricultural extension workers have difficulty identifying pests in the field as they lack specialized training in insect taxonomy. However, field workers can make fairly accurate identification of pests by linking pests to particular crop damage symptoms. This approach is particularly useful for pests which move away from the crop after they cause damage and may be unavailable to collect and identify at the time of field visits.

Vegetable pests feed on different parts of the plants. The pests can be grouped according to the plant parts they damage, e.g. root feeders/soil-borne pests, leaf and stem feeders and flower and fruit feeders, e.g. caterpillars of certain moths, fruit flies and certain fungal pathogens. Some pests, (e.g. plant-parasitic nematodes, leaf-feeding mites and caterpillars of certain moths, whiteflies, fruit flies, leaf miner flies, certain species of aphids, and some fungal pathogens), have a wide host crop range and cause economic damage to many vegetable crops. Other pests, such as bacterial pathogens, have a narrow host crop range and cause economic damage to just one or two vegetable crops.

Weeds damage vegetables by competing with them for nutrients, space, and sunlight. Weeds also habour certain pests and diseases, enabling the pests/diseases to survive during periods when their preferred food crops are absent, especially after the death of their primary hosts. Weeds therefore serve as reservoirs of certain pests and diseases. Information on pests, their host plants and pest monitoring techniques can be summarized into pest fact sheets. A field guide on pests of target crops is simply a comprehensive collection of fact sheets. Such field guides are a useful information resource for extension workers which they can use to identify, assess, report and advise on the pest situations in their localities.

Information on pest identity, biology, host plants, damage symptoms, natural enemies and monitoring techniques can be summarized into fact sheets. Such fact sheets are useful information resources for extension workers in their work to identify, assess, report and advise on the pest situations. The fact sheets and related pest lists (Appendices 3 to 8) presented here come from the results of diagnostic surveys of vegetable agroecosytems in Benin. The fact sheets cover recognition of pests, their biology and economic importance. While the fact sheets relate to Benin, they will also help extension workers in other West African countries to get familiar with pests they are likely to encounter in vegetable agroecosystems.

Root and soil-borne pests

Insects

Figure 48. The mole cricket, *Gryllotalpa africana*. (Photo: G. Goergen/IITA)

Mole cricket, *Gryllotalpa africana*

Recognition: The mole cricket, *Gryllotalpa africana*, occurs in moist soils. It cannot survive underwater so it is not found in flooded soils. The mole cricket is large in size, dark brown in colour, and has dense fine hairs covering its body (Figure 48). The insect's forelegs are enlarged and used for digging tunnels and burrows in moist soil. The 'neck region' (called the prothorax) is enlarged; it helps the insect to push its way through the soil. The hind wings are rudimentary and do not cover the whole abdomen. Mole crickets are easy to recognise as they leave small mounds of soil and frass on the soil surface as they move and feed in the tunnels.

Biology: The life cycle of the mole cricket consists of eggs, nymphs and adults. The female lays eggs underground and the eggs hatch within two to four weeks. The insect stays in the tunnels during the day and comes out at night in search of food.

Economic importance: *Gryllotalpa africana* feeds on roots of a wide range of vegetables and on soil invertebrates. The insect is a minor pest of vegetables, usually of local importance. Nymphs and adults are the damaging stages of the mole cricket. The insect can carry and feed on vegetable seeds in the tunnels and thereby reduces germination of seeds sown directly. The insect also damages and kills young plants by feeding on their roots in seed beds. The pest cannot kill older plants because their root systems are larger and more robust than those of young plants. Crop damage usually occurs in patches of the field.

Method of spread: Adult mole crickets are winged but they are not strong fliers.

Plant parasitic nematodes

Root-knot nematodes, *Meloidogyne* spp.

Recognition: Root-knot nematodes (RKN), *Meloidogyne* spp., are common plant parasitic nematodes which live in the soil and plant tissues and attack vegetables. They are microscopic (invisible to the naked eye) organisms, but they can be recognised by the damage symptoms they cause on plants. Female RKN are whitish and spherical with a slender neck (like a gourd) (Figure 49); males are small, tiny, thin and wormlike. RKN species extracted from roots of five most important vegetables in Benin are *Meloidogyne javanica*, *M. incognita*, *M. arenaria*, *M. exigua*, and *M. chitwoodi*.

Figure 49. Female (left) and male (right) of the root-knot nematode. (Photo: G. Goergen/IITA)

Biology: The life cycle of RKN consists of eggs, larvae (known as juveniles) and adults, each of which can occur in soil or inside roots and plant foliage. Adult males live in the soil. Females live in roots and immature females may leave one root and enter another where they remain and mature. A female produces between 500 and 1500 eggs in egg sacks, and releases the eggs into the soil. The life-cycle of RKN is one month. The eggs hatch into young nematodes (known as juveniles), which moult four times before becoming adults.

Economic importance: *Meloidogyne* species are economically important pests of a wide range of vegetables including the African garden eggplant, aubergine, basil, carrot, lettuce, okra, pepper and tomato. The second stage juvenile is the infective stage of the pest; it enters, feeds on and damages vegetable roots. The damage symptoms appear as galls along the root surface (Figure 37; Figure 50), loss of root mass (Figure 38), yellowing (chlorosis) of leaves, and stunted growth. The damage causes poor growth and death of plants, leading to patchy distribution of the plants on vegetable plots. Appendix 9 shows the distribution of damage (galling) caused by root-knot nematodes on the African garden eggplant in Benin.

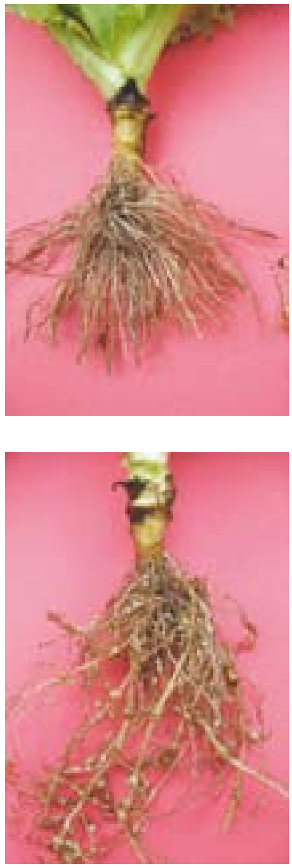


Figure 50. Healthy lettuce roots (above) and damaged by root-knot nematodes (below). (Photo: B. James/IITA)

Method of spread: *Meloidogyne* species are spread by movement of infected plant residues and soil (especially for egg stages), and by sticking to footwear and farming tools. RKN are also spread by rain, irrigation and runoff water. RKN and other plant parasitic nematodes survive as eggs during the periods when susceptible host plants are absent. This enables the pests to stay dormant for many years without any reduction in their ability to reproduce and attack plants when conditions become favourable afterwards. It is therefore difficult to get rid of plant parasitic nematodes at vegetable production sites.

Lesion nematodes

Lesion nematodes are plant parasitic nematodes which do not cause galls on root surfaces or knotting of the roots.

Pathogens

Figure 51. Lettuce plants damaged by the bacterium *Erwinia carotona*. (Photo: B. James/IITA)

Bacterium, *Erwinia carotovora*

Recognition: The bacterium *Erwinia carotovora* occurs in soil, stems and leaves which are in close contact with the soil. The pathogen is invisible to the naked eye, but the damage symptoms it causes are easily recognisable. In lettuce, the bacterium causes rotting of leaf edges, especially of older leaves at the base of the plant. The damage later spreads to leaves of the whole plant, and finally to the bunch of leaves that form the crown of the plant, which dissolves into a slimy rotting mass (Figure 51) which has a fishy smell.

Economic importance: *Erwinia carotovora* damages foliage of a wide rage of vegetables e.g. beans, cabbage, garlic, ginger, lettuce, onion, peppers and tomato and many other non-vegetable crops. The bacterium is an economically important pest of lettuce.

Method of spread: *Erwinia carotovora* is spread via infected plant debris and soil on farm tools and footwear. The bacterium moves from the soil to the leaves of plants in splashes of rain and irrigation water.

Bacterium, *Ralstonia solanacearum*

Recognition: The bacterium *Ralstonia solanacearum* lives in the soil and the damage symptoms it causes are easily recognised. The bacterium causes rapid wilting of the entire plant (Figure 52). Damage symptoms begin on the youngest leaves which become flaccid. This is followed by rapid wilting of the plant without yellowing of the leaves. The vascular system of infected plants is discoloured, which is best seen in a longitudinal section of stems.

Figure 52. Tomato plants damaged by the bacterium *Ralstonia solanacearum*. (Photo: R. Sikirou/INRAB)

Economic importance: *Ralstonia solanacearum* damages the foliage of a wide range of vegetables e.g. aubergine, beans, ginger, groundnut, pepper, tobacco and tomato and many other non-vegetable crops. The bacterium is an economically important pest of tomato.

Method of spread: *Ralstonia solanacearum* is spread by irrigation water, contaminated soil, infected seeds, plant debris, farming tools, footwear and through diseased transplants.

Figure 53. V-shaped lesion on tip (top left) of cabbage leaf caused by the bacterium *Xanthomonas campestris* pv. *campestris.* (Photo: B. James/IITA)

Edible plants in the family *Brassicaceae* (also called *Cruciferae*) are termed **cruciferous** vegetables.

Figure 54. Cabbage leaf drying and defoliation caused by the bacterium *Xanthomonas campestris* pv. *campestris*. (Photo: B. James/IITA)

Bacterium, *Xanthomonas campestris* pv. *campestris*

Recognition: The bacterium *Xanthomonas campestris* pv. *campestris* occurs in tissues of its host plants at any growth stage and is recognized by the damage symptoms it causes. In young plants of cabbage that germinate from infected seeds, the cotyledons are discoloured at the edges. Diseased cotyledons fall off prematurely. In older plants, the damage symptoms appear as yellow v-shaped lesions on the leaves, usually along the edges of the lower leaves (Figure 53). The 'v' commonly points toward a vein. As the disease advances, the leaf veins turn dark brown to black, the leaves wilt and early defoliation starts to occur (Figure 54). Severe infection by the pathogen causes dieback and rotting of cabbage heads or deformities.

Economic importance: *Xanthomonas campestris* pv. *campestris* damages the foliage of brussels sprout, cabbage, cauliflower, radish, and other crops. The bacterium is economically important pest in cabbage production.

Method of spread: *Xanthomonas campestris* pv. *campestris* survives on plant debris left in the soil and on cruciferous weeds. The pathogen spreads via infected seeds, cruciferous weeds, contaminated plant debris, soil, farming tools, footwear and water splashes e.g. during irrigation. It is commonly spread in waterlogged seed beds.

Fungus, *Fusarium oxysporum* f. sp. *lycopersici*

Recognition: The fungus *Fusarium oxysporum* f. sp. *lycopersici* occurs mainly on root systems. Disease-causing units of the fungus are spores (equivalent to seeds in flowering plants). When in contact with roots, the spores penetrate and invade the root tissues. The spores grow into mycelia (equivalent to branches in flowering plants) within the tissues and disrupt water and mineral intake by the plant. Affected leaves wilt and die, but remain attached to the stem (Figure 55). Vascular tissue of infected plants appear red-brown; the discoloration can be seen when the stem is split open along its length. Tomato seedlings infected by the fungus become stunted and their older leaves turn yellow.

Figure 55. Tomato leaf blighting caused by the fungus *Fusarium oxysporum*. (Photo: R. Sikirou/ INRAB)

Economic importance: *Fusarium oxysporum* f. sp. *lycopersici* damages roots of tomato, and the fungus is an economically important pest of tomato.

Method of spread: *Fusarium oxysporum* f. sp. *lycopersici* grows best in warm soils with low moisture content. Once introduced into the soil, the fungus can survive in the soil for many years, and spread via contaminated soil, farm tools, footwear, seeds, in infected transplants, and in rain and water splashes during irrigation.

Figure 56. Amaranth plants with 'damping-off disease' symptoms of the fungus *Phytophtora* spp. (Photo: R. Sikirou/INRAB)

Fungus, *Phytophtora* spp.

Recognition: *Phytophtora* species occur mainly on roots, stems and foliage of plants. Spores of the fungus germinate and enter plant tissues, causing water-soaked spots at the points of entry. The spores grow into mycelia inside the plant, causing drying up of the roots ('dry rot disease') and foliage. The water soaked areas turn a chocolate brown colour. In amaranth, infected leaves and stems have large, irregular and brown necrotic lesions (localized dead tissues) and the leaves wilt. 'Damping-off disease' refers to these symptoms on the foliage. Usually, damping-off appears on a branch first and later spreads to the entire plant, causing rapid blighting (Figure 56).

Economic importance: *Phytophtora* species damage roots and foliage of a number of vegetables e.g. the African garden eggplant, amaranth, bean, pepper, potato and tomato. The pathogen is an economically important pest of amaranth and tomato. Dry rot caused by *Phytophtora* species kills seedlings more easily than mature plants. Rapid blighting caused by the fungus occurs mostly during warm moist periods, such as in the rainy season, when it can cause 100% crop loss.

Method of spread: Warm wet conditions favour rapid growth of *Phytophtora* species. The fungus survives for years in moist soils, even in the absence of suitable host plants, and is spread via decaying plant tissues. Fungal spores are also spread by rainwater, runoff water (e.g. during irrigation), and movement of contaminated plant parts, soil and equipment.

Fungus, *Sclerotium rolfsii*

Recognition: The fungus *Sclerotium rolfsii* occurs in the soil and on plant debris. Infected plants show progressive yellowing and wilting of the leaves (Figure 57). The pathogen is best recognized by a white mat of fungal mycelia on the bases of infected stems (Figure 58) or just below the soil surface (Figure 59) and on leaf debris. The thick white mat of mycelia bears many small, hardened spherical resting bodies known as sclerotia. The sclerotia are initially white in colour but later turn dark brown. The fungus causes damping-off, root rot (Figure 60) and fruit rot. Infected seedlings develop dark brown lesions at stem bases. In older woody plants (e.g. pepper) the lesions girdle the stem base, slowly killing the plant.

Economic importance: *Sclerotium rolfsii* damages roots of a wide range of vegetables including the African garden eggplant, bean, cabbage, carrot, ginger, lettuce, okra, pepper, tomato, *Venomia amydalina* ('bitter leaf'), and many other non-vegetable crops. The pathogen is an economically important pest of tomato and pepper.

Method of spread: *Sclerotium rolfsii* survives in moist soil and host plant debris that is not fully decomposed. Compost and manure which is composed of host plant debris are sources of the fungus. The fungus is also spread via infected seeds, farming tools and by rainwater or wind.

Figure 57. Pepper plants attacked by the fungus *Sclerotium rolfsii*. (Photo: B. James/IITA)

Figure 58. Basal stem of pepper plants showing white mat (mycelia) of the fungus *Sclerotium rolfsii*. (Photo: B. James/IITA)

Figure 59. Mycelia (white mat) of the fungus *Sclerotium rolfsii* on pepper. (Photo: B. James/IITA)

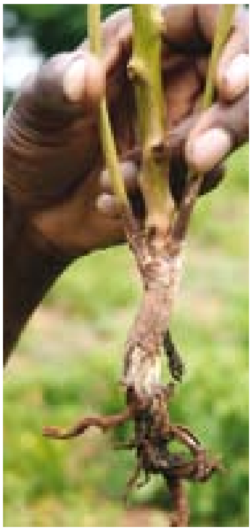


Figure 60. Basal stem and roots of pepper killed by the fungus *Sclerotium rolfsii*. (Photo: B. James/IITA)

Leaf and stem pests

Insects

Figure 61. Adult of the beet webworm, *Spoladea recurvalis*. (Photo: G. Goergen/ IITA)

Figure 62. Amaranth leaves damaged by caterpillars of the beet webworm, *Spoladea recurvalis*. (Photo: B. James/IITA)

Beet webworm, *Spoladea recurvalis*

Recognition: Moths of *Spoladea recurvalis* (also known as *Hymenia recurvalis*) are dark-brown in colour with two white stripes across the anterior of their hind wings (Figure 61). Young caterpillars are green in colour, with a transparent epidermis (skin), two longitudinal white bands along the body and a dark band in the middle of the white stripes. Mature caterpillars become reddish in colour before falling to the ground to pupate inside cocoons, just below the soil surface. Caterpillars roll amaranth leaves into distinctive leaf shelters, and 'skeletonize' the foliage, leaving only the main leaf veins intact (Figure 62). Leaf shelters are indicative of the presence of *S. recurvalis*.

Biology: Females of *S. recurvalis* lay tiny eggs, singly or in batches on the undersides of leaves. Each female lays up to 200 eggs in its lifetime of 12 to 15 days, and in a week the eggs hatch into larvae (known as caterpillars). The larval stage lasts for three to four weeks, and the insect produces many generations in a year. Natural enemies of *S. recurvalis* include the parasitoid *Trichogramma* spp. (which kill the eggs), and *Apanteles*, *Campoletis*, *Cardiochiles*, *Chelonus*, *Phanerotoma* and *Prosopodopsis*, which kill the caterpillars. These natural enemies are not pest-specific.

Economic importance: *Spoladea recurvalis* damages leaves of a number of vegetables e.g. amaranth, aubergine, bean, beetroot, cucurbits (e.g. melon, watermelon) and other non-vegetable crops. The insect is an economically important pest of amaranth. Caterpillars feed voraciously and cause severe leaf loss. Within a short time, the caterpillars destroy the entire foliage of amaranth by 'skeletonizing' the leaves (Figure 62). Young plants are prone to this kind of damage. Appendix 9 shows distribution of damage severity levels of *S. recurvalis* on amaranth in Benin.

Method of spread: Moths of *S. recurvalis* are good fliers; the caterpillars crawl from plant to plant.

Leaf caterpillar, *Phycita melongenae*

Recognition: Moths of *Phycita melongenae* are small and brown in colour with light black dots on the wings. Caterpillars of the moth are greenish in colour with white stripes running along the body. The characteristic leaf shelters (Figure 63) made by caterpillars of the insect indicate the presence of this pest.

Figure 63. Characteristic leaf shelters of leaf caterpillar, *Phycita melongenae.* (Photo: B. James/ IITA)

Biology: Females of *P. melongenae* lay eggs singly or in batches on the leaves of the crop. The eggs hatch into caterpillars which live and feed in leaf shelters. The caterpillar stage lasts for about two months before they pupate and hatch into moths. Natural enemies that are specific to *P. melongenae* are unknown in Benin.

Economic importance: *Phycita melongenae* damages the leaves of the African garden eggplant, aubergine and okra. The insect is an economically important pest of the African garden eggplant and aubergine. Caterpillars cause severe leaf loss by rolling leaves into leaf shelters and defoliating the plant. The most severe damage is usually to the leaves at the apex of plants.

Method of spread: Moths of *P. melongenae* fly and the caterpillars crawl from plant to plant.

Figure 64. Adult of the leaf caterpillar, *Selepa docilis*. (Photo: G. Goergen/IITA)

Figure 65. Caterpillar of *Selepa docilis* on the African eggplant. (Photo: B. James/IITA)

Figure 66. Leaves of the African eggplant skeletonized by caterpillar of *Selepa docilis*. (Photo: B. James/IITA)

Leaf caterpillar, *Selepa docilis*

Recognition: Moths of *Selepa docilis* are brown in colour (Figure 64). The caterpillars are covered with long grey hairs, are pale green in colour with yellowish stripes on the back and a small black spot on each side. The presence of the pest is usually indicated by small groups of young caterpillars clumping together close to where they hatched on the plant (Figure 65).

Biology: Female moths lay eggs singly and very often at the edge of leaves. The eggs hatch in four to nine days. Mature caterpillars pupate in conical cocoons on the leaves. Adult moths mate soon after emerging. *Selepa docilis* can produce many generations in a year. Natural enemies that feed specifically on *S. docilis* are yet to be reported in Benin. Certain large-sized wasps (e.g. *Polistes marginalis*, *Polybioides tabidus*, *Ropalidia cincta*), predatory bugs and birds feed on the caterpillars. However, these natural enemies also feed on a wide range of other insects and are not specific to *S. docilis*.

Economic importance: *Selepa docilis* is an economically important pest of the African garden eggplant and aubergine. Caterpillars feed voraciously on the leaves and defoliate plants by 'skeletonizing' the leaves except for the main leaf veins (Figure 66). The damage causes severe leaf loss. Appendix 9 shows the distribution of damage severity levels of *S. docilis* on the African garden eggplant in Benin.

Method of spread: Moths of *S. docilis* are active fliers and caterpillars crawl from plant to plant.

Leaf caterpillar, *Psara basalis*

Recognition: Moths of *Psara basalis* are small, yellowish in colour and have fine black specks on their wings. Caterpillars of *P. basalis* are greenish white in colour with green stripes running along the body. Young caterpillars (Figure 67) fold amaranth leaves into shelters (Figure 68) and live inside them. The presence of leaf shelters indicates the presence of *P. basalis*.

Biology: Female moths lay eggs on the leaves and the eggs hatch into caterpillars in about a week. The caterpillar stage lasts for three to four weeks. In amaranth, mature caterpillars migrate to the inflorescence where they pupate in cocoons. *Psara basalis* produces many generations in a year. Natural enemies that are specific to *P. basalis* are yet to be reported in West Africa. The parasitoid *Hypomicrogaster botydis* attacks and kills caterpillars of some other insects including those of *P. basalis*.

Economic importance: *Psara basalis* damages the leaves of amaranth, beetroot, cucurbits and radish. The insect is more economically important on amaranth than on any other vegetable in Benin. The caterpillars stay inside the leaf shelters, feed on the leaves and fill the 'shelters' with their excrement. Within a short time, the caterpillars skeletonize the leaves (Figure 69). Generally, young plants are prone to this kind of damage. Appendix 9 shows the distribution of damage severity levels of *P. basalis* on amaranth in Benin.

Method of spread: Moths of *P. basalis* fly actively; the caterpillars can crawl from plant to plant.

Figure 67. Caterpillar of *Psara basalis* on amaranth. (Photo: B. James/IITA)

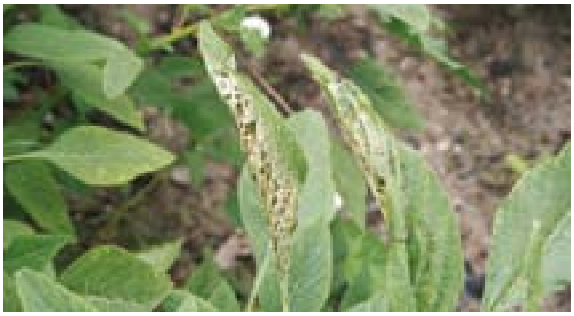


Figure 68. Amaranth leaves folded and damaged by caterpillars of *Psara basalis*. (Photo: B. James/IITA)

Figure 69. Amaranth plant damaged by caterpillars of *Psara basalis.* (Photo: B. James/IITA)


Figure 70. Adult of the diamond back moth, *Plutella xylostella*. (Photo: G. Goergen/IITA)


Figure 71. Papery leaf epidermis damage symptoms caused by diamond back moth, *Plutella xylostella*, on cabbage. (Photo: B. James/IITA)

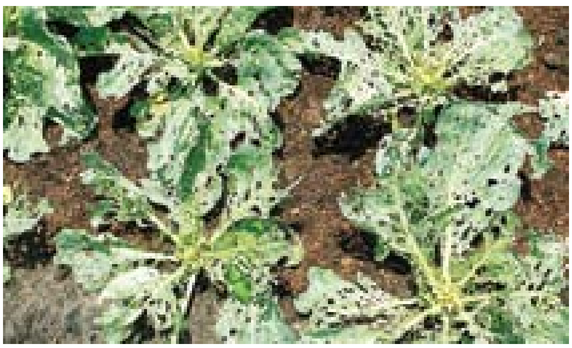


Figure 72. Cabbage plants destroyed by caterpillars of the diamond back moth, *Plutella xylostella*. (Photo: B. James/IITA)

Diamond back moth, *Plutella xylostella*

Recognition: Moths of the diamond back moth (DBM), *Plutella xylostella*, are small, slender, about 6 mm long and brown in colour (Figure 70). There are three triangular marks on the edge of each of the wings covering the body. These wings have a fringe of hairs. The eggs are oval in shape and yellowish in colour. Caterpillars of DBM are green in colour (Figure 36), sometimes tinged with pale yellow with distinctive body segments. The pupae live in silky transparent cocoons which are about four times longer than their width. DBM larvae and pupae often occur on the undersides of leaves; they also occur in between young leaves of cabbage heads. The presence of DBM in vegetable fields is easily recognised by typical 'windowing' (see Economic importance below) or defoliation of leaves caused by caterpillars (Figure 71).

Biology: Female DBM live for a little over two weeks. Each female can lay 50–150 eggs during its lifespan. The eggs are laid either singly or in groups of two to three eggs, often along the midrib of leaves. Two to three days after being laid, the eggs hatch into caterpillars; caterpillars moult four times and pupate. The pest produces up to ten generations in a year. Parasitoids, e.g. *Cotesia plutellae*, are common natural enemies of DBM caterpillars, which are also killed by entomopathogens.

Economic importance: DBM is an economically important pest of brassica crops. On cabbage, DBM caterpillars voraciously eat chlorophyll from the undersides of leaves, growing bud and cabbage heads. The damage leaves a papery epidermis of the upper leaf surface intact and translucent windows in the leaf blades; this damage symptom is called 'windowing' or 'fenestration'. The 'windows' later break down and appear as irregular holes in the leaves, resulting in complete loss of the crop (Figure 72). Appendix 9 shows the distribution of damage severity levels of DBM in Benin.

Method of spread: DBM moths are not good fliers and cannot fly for long distances. However, they are often carried over long distances by wind and by transport of infested plant parts by man.

Cabbage webworm, *Hellula undalis*

Recognition: Moths of *Hellula undalis* are brown in colour and triangular in shape when at rest. The hind wings have light brown lines in a zig-zag pattern. The eggs are creamy white in colour; the caterpillars are creamy white in colour with dark brown or black heads and light pinkish-brown stripes along the length of the body. Cocoons of the pupa stage occur on the plant or in the soil. The presence of *H. undalis* in vegetable fields is usually indicated by the appearance of multiple cabbage heads per plant (Figure 73), and large quantities of frass produced by the caterpillars in between leaf surfaces. The presence of frass is usually the first noticeable sign of infestation.

Figure 73. Multiple heads of cabbage caused by the cabbage worm, *Hellula undalis*. (Photo: B. James/IITA)

Biology: Female *H. undalis* lay over 100 eggs either singly or in small groups of four or six eggs. The moth usually lays eggs at the bases of young leaves, often near the terminal bud. Eggs hatch into caterpillars two to five days after they are laid. The caterpillar stage lasts for about one week before pupating on the plant or in the soil. Caterpillars spin a protective web around themselves in between leaf surfaces. *Hellula undalis* can produce up to 12 generations a year. The caterpillars are killed by many different species of parasitoids, e.g. *Apanteles*, *Agathis*, *Bracon*, *Casinaria*, *Diadegma*, *Microchelonus*, *Pristomerus*, *Trathala* and *Venturia*. However, natural enemies that are specific to *H. undalis* are unknown in Benin.

Economic importance: *Hellula undalis* damages leaves of broccoli, cabbages, radish and sometimes aubergine. The pest is economically important in cabbage production. Newly hatched caterpillars feed on young tender leaves surrounding the terminal bud of cabbage and bore into the main veins of leaves. The caterpillars later penetrate, feed on and destroy the terminal bud of the plant. This prevents formation of cabbage heads. Mature plants respond by producing many growing points and the plant responds ('compensates') by forming several small heads on the plant (Figure 73). These small heads are unsuitable for consumption or sale, resulting in severe food and economic losses. If cabbage seedlings or young plants are attacked by *H. undalis*, the plants wilt and die quickly, causing severe losses in cabbage nurseries and newly transplanted cabbage fields.

Method of spread: Moths of *H. undalis* actively fly over long distances. The pest can also be spread by the movement of infested plant parts by man.

Figure 74. Wingless adult of the false cabbage aphid, *Lipaphis erysimi*. (Photo: A. Staverløkk/Bioforsk)

Figure 75. Winged adults of the false cabbage aphid, *Lipaphis erysimi*. (Photo: A. Staverløkk/Bioforsk)

Figure 76. Colonies of the false cabbage aphid, *Lipaphis erysimi*. (Photo: G. Goergen/IITA)

Figure 77. Cabbage plot damaged by the false cabbage aphid, *Lipaphis erysimi*. (Photo: B. James/IITA)

False cabbage aphid, *Lipaphis erysimi*

Recognition: *Lipaphis erysimi* is an aphid which is greyish-green to blackish-green in colour. The adults can be wingless (Figure 74) or winged (Figure 75). Adults and nymph aphids live in colonies, mostly on the underside of cabbage leaves and on young shoots (Figure 76).

Biology: *Lipaphis erysimi* reproduces without mating (known as parthenogenesis). The females do not lay eggs but give birth to live nymphs (known as viviparous reproduction). Each female can produce up to 160 nymphs during its lifetime. The nymphs moult four times before becoming adults. As soon as the last nymph becomes an adult, it starts to reproduce and at a time when its 'mother' is still in the colony and reproducing. Therefore, generations of aphids will overlap in colonies of the insect. The life cycle of the false cabbage aphid lasts for three weeks to a month, and the aphid can produce six overlapping generations before the cabbage crop is harvested. Natural enemies of the aphid include predators e.g. ladybird beetles (Figure 22 and 23), larvae of hoverflies (Figure 25), larvae of lacewing flies and parasitoids (Figure 20 and 21).

Economic importance: *Lipaphis erysimi* damages the leaves of aubergine, cabbage, radish and turnip. The insect is an economically important pest of cabbage and turnip. In cabbage, the damage symptoms are rolling of young leaves, yellowish patches (chlorosis) on leaves (Figure 77), shortening of internodes and distortion and dwarfing of plants. *Lipaphis erysimi* is also a vector of viruses that cause diseases in plants.

Method of spread: The false cabbage aphid *L. erysimi* spreads by active flight of winged adults, by being carried in wind currents and by movement of infested plant parts by man. The weed *Chromolaena odorata* is a wild host plant of *L. erysimi* and a source of infestation by the aphid.

Leaf miner fly, *Liriomyza* spp.

Recognition: Adults of the leaf miner fly (LMF), *Liriomyza* spp., are tiny (about 2 mm long) and black and yellow in colour ((Figure 78). The presence of LMF in vegetable fields is indicated by the whitening of leaf surfaces reflected by leaf mines made by LMF larvae as they feed (Figures 79 and 80).

Biology: Female LMF lay their eggs on leaves. The eggs hatch into larvae known as maggots. The larvae live inside tunnels beneath the leaf epidermis. When fully grown, the larvae cut a hole in the leaf and drop to the ground to pupate in the soil. Certain parasitoids e.g. *Encarsia* spp. kill larvae of *Liriomyza* spp.

Economic importance: *Liriomyza* species damage leaves of a wide range of vegetables e.g. the African garden eggplant, amaranth, cabbage, cucumber, lettuce, tomato and many other non-vegetable crops. The insect is an economically important pest of many vegetables, but it is of minor importance in Benin. The larvae of LMF feed on leaf chlorophyll by mining their way through the leaf tissue just beneath the epidermis of leaf surfaces. As they move and feed in different directions, the damage appears as whitish tunnels on leaf surfaces (Figures 79 and 80). The whitish tunnels are particularly prominent on leaves of cucumber, pumpkins, water-melon and other cucurbit vegetable plants. Heavy infestations of LMF can kill seedlings and encourages fungal diseases to develop in the leaves.

Method of spread: Adult LMF disperse by flying.

Figure 78. Adult of leaf miner fly, *Liriomyza* sp. (Photo: B. James/IITA)

Figure 79. Tunnels caused by leaf miner fly, *Liriomyza* sp., on lettuce leaf. (Photo: B. James/IITA)

Figure 80. Tunnels caused by leaf miner fly, *Liriomyza* sp., on pumpkin leaf. (Photo: B. James/IITA)

Figure 81. Adults of the whitefly, *Bemisia tabaci*, as seen under a microscope. (Photo: G. Goergen/IITA)

Figure 82. Nymphs of the whitefly, *Bemisia tabaci*, as seen under a microscope. (Photo: G. Goergen/IITA)

Whitefly, *Bemisia tabaci*

Recognition: Adults, nymphs and pupae of the whitefly, *Bemisia tabaci*, occur on the undersides of young leaves. Adults of the whitefly are small (about 1 mm long). The males are slightly smaller than the females. The wings are brilliantly white (Figure 81), as are those of the spiralling whitefly, *Aleurodicus dispersus*. However, adults of *B. tabaci* are much smaller than those of spiralling whiteflies, are not covered with large amounts of white waxy material and do not lay their eggs in distinctive spirals. Older nymphs of *B. tabaci* are sessile and appear as pale yellow oval specks to the naked eye (Figure 82).

Biology: A female *B. tabaci* can lay up to 160 eggs on the undersides of leaves in its life time of up to two months. The eggs hatch into nymphs (larvae) in a week. Newly hatched nymphs (or crawlers) are the only mobile nymph stage of the insect. Crawlers move to, and settle at, suitable feeding locations on lower leaf surfaces and become sessile throughout the remaining nymphal stages. The *B. tabaci* whitefly can produce 11 to 15 generations in a year. Many species of parasitoids e.g. *Encarsia* and *Eretmocerus* kill nymphs of *B. tabaci*. Ladybird beetles are predators of whitefly nymphs.

Economic importance: *Bemisia tabaci* damages leaves of a wide range of vegetables e.g. the African garden eggplant, aubergine, beans, cucumber, lettuce, okra, pepper and tomato, and a number of other non-vegetable crops. The whitefly is an economically important pest of many vegetable crops. Adults and nymphs of the insect suck sap from the leaves, but this does not cause a lot of physical damage to the plants. The main damage is caused by viruses, e.g. Tomato Yellow Leaf Curl Virus (TYLCV) which causes tomato yellow leaf curl disease. Tomato plants infected with the TYLCV develop erect branches with small chlorotic leaflets which are stunted and cup and twist upward (known as leaf cupping). In severely affected tomato plants, flowers abort and fruit set fails. Whiteflies also secrete honeydew that encourages the growth of black sooty mould (fungus) on plant leaves and stems. Sooty mould can disrupt the plant's ability to absorb light which is needed for photosynthesis.

Method of spread: Adult whiteflies are not good fliers. However, once airborne, they can be carried by wind over long distances. Also, all developmental stages of the pest can be carried from one place to another on the leaves and foliage of host plants.

Plant bug, *Helopeltis schoutedeni*

Recognition: The plant bug, *Helopeltis schoutedeni*, is small (about 9 mm length) with prominent eyes and a red or orange-coloured body (Figure 83). The antennae are black in colour and are longer than the body. The females have knife-like ovipositors which they use to insert eggs into plant stems or leaves. The nymphs are very elongated, have long legs and antennae and are initially yellow-whitish in colour with red dots and bands on the body.

Figure 83. Adult of *Helopeltis schoutedeni*. (Photo: G. Goergen/IITA)

Biology: Eggs of *H. schoutedeni* hatch into nymphs. Each nymph moults several times before becoming an adult. The insect can produce several generations in a year. Red ants (*Oecophylla smaragdina*) feed on *H. schoutedeni*; certain parasitoids also attack the pest.

Economic importance: *Helopeltis schoutedeni* feeds on the leaves, flowers and fruits of a number of vegetables including the African garden eggplant, beans and non-vegetable crops. Nymphs and adults of *H. schoutedeni* are the damaging stages of the pest. They feed by piercing and sucking sap from the leaves, flowers and fruits of the plant. As they feed, they release toxins into the plant and cause dead (necrotic) spots at the points where they pierce the plant to suck the sap. Leaves damaged by the bug fall prematurely. Young plants that are attacked become stunted. The insect is a minor pest of vegetables, usually of local importance.

Method of spread: Adults of *H. schoutedeni* are good flyers and spread by flying.

Figure 84. Green stink bug, *Nezara viridula*. (Photo: G. Goergen/IITA)

Green stink bug, *Nezara viridula*

Recognition: Adults of *Nezara viridula* are large, flat, and entirely green (Figure 84). The green bug, *Acrosternum acutum*, resembles *N. viridula* in size, shape, colour, behaviour, host range and in crop damage symptoms, but adults of *A. acutum* have pointed thorns on the neck area (pronotum) and the pronotum of *N. viridula* is round.

Biology: The female green stink bug lays about 300 eggs in groups on the underside of leaves. The eggs hatch into nymphs. Young nymphs group together; older nymphs disperse to other areas of the plant and vegetable plots. The nymphs moult five times in about a month before becoming adults.

Economic importance: *Nezara viridula* damages young shoots of a number of vegetables e.g. African eggplant, amaranth, cabbage, okra, peas and tomato. Larvae and adults of the insect pierce and suck sap from young shoots, causing wilting of plant parts. The insect is a minor pest of vegetables, usually of local importance.

Method of spread: *Nezara viridula* disperses by flying and crawling between plants

Beetle, *Gasteroclisus rhomboidalis*

Recognition: Adults of the beetle, *Gasteroclisus rhomboidalis*, are yellowish or whitish in colour with a black spot on their back. The beetle is elongated and covered with dense fine hairs. The antennae are bent and look like an elbow. The upper body surface has two 'v-shaped' brown lines at the anterior and a slightly larger black spot at the posterior. *G. rhomboidalis* damages the stems of amaranth. Affected stem bases swell up and the grubs can be found inside the swollen stem parts (Figure 85).

Biology: Adult females of the beetle dig a hole in the stem and lay eggs in it. The eggs hatch into larvae known as grubs.

Economic importance: *Gasteroclisus rhomboidalis* feeds on amaranth but is a minor pest of the crop, usually of local importance. Grubs of the beetle tunnel into and feed on stems, usually stem bases in the soil. Severe attacks by the beetle kill amaranth plants, especially amaranth seedlings.

Method of spread: Transplanting amaranth seedlings infected with eggs or grubs of the beetle is a major way of spreading the pest.

Figure 85. Swollen and puctured basal stems of amaranth caused by grubs of the beetle, *Gasteroclisus rhomboidalis*. (Photo: B. James/IITA)

Figure 86. Ladybird beetle, *Epilachna elaterii*. (Photo: G. Goergen/IITA)

Ladybird beetle, *Epilachna elaterii*

Recognition: Adults of the ladybird beetle, *Epilachna elaterii*, are small, oval in shape and reddish-orange in colour (Figure 86). They have 12 black spots arranged in two longitudinal rows on each of the hard wings that cover the body. Each of the black spots is surrounded by a light coloured area. The larvae are oval in shape with several black spines that are branched and located in six rows along the length of the body. The pupae are yellow and remain attached to the leaf surface with the help of the spines.

Biology: Female *E. elaterii* beetles lay up to 200 eggs in about a month. The eggs are laid in groups of 5 to 40 on the undersides of leaves. Within a week of being laid, the eggs hatch into larvae. Young larvae initially remain grouped together at the points where they hatched, but they later spread to other parts of the plant.

Economic importance: Ladybird beetles are best known as predators of other insects. However, *E. elaterii* and certain other species of ladybird beetles are plant feeders. *Epilachna elaterii* damages the leaves of a number of crops including the African garden eggplant, amaranth, cucumber, melon, lettuce and pumpkin. The insect is a minor pest of the crops, usually of local importance (e.g. on cucumber, melon, pumpkin). The larvae and adults of *E. elaterii* feed on chlorophyll scraped from the undersides of the leaves. The damaged leaves become pale or brown translucent membranes with only the leaf veins remaining intact. Damaged leaves become greyish and dry.

Method of spread: *Epilachna elaterii* disperse by flying.

Weevil, *Hypolixus nubilosis*

Recognition: Adults of the weevil are dark brown in colour with white and light brown spots (Figure 87). The larvae are are white in colour.

Biology: Adult females lay eggs in cavities on stems and leaf petioles. The female weevil lays on average over 400 eggs in its lifetime of about three and half months. The eggs hatch into larvae known as grubs.

Economic importance: *Hypolixus nubilosis* feeds on leaves and stems of amaranth, cabbage, cucumber and lettuce. The insect is a minor pest of these crops, usually of local importance. Grubs of the weevil bore into main stems of plants as they feed. They pupate inside main stems or roots.

Method of spread: Adults of the weevil fly over short distances.

Figure 87. Weevil, *Hypolixus nubilosis*. (Photo: G. Goergen/IITA)

Mites

Figure 88. Leaf tapering caused by the broad mite, *Polyphagotarsonemus latus*, on the African eggplant. (Photo: B. James/IITA)

Broad mite, *Polyphagotarsonemus latus*

Recognition: The broad mite, *Polyphagotarsonemus latus*, lives on the underside of leaves. The mites are tiny, broad in shape and yellowish white in colour. Because of their tiny size, broad mites appear as specks to the naked eye and are best seen under a hand lens or a binocular microscope. The presence of broad mites is obvious by the damage they do to the crop (Figure 88).

Biology: Populations of the broad mite consist of eggs, nymphs and adults. The female lays eggs singly, usually in small depressions on the undersides of leaves, tender stems, flowers and fruits. The pest is abundant in warm dry weather. The lifecycle of the broad mite lasts for a little more than a week. Predatory mites (phytoseiids) are common natural enemies of the broad mite. Phytoseiids are tiny and resemble pest mites but their body is shinier and they move faster than pest mites.

Economic importance: *Polyphagotarsonemus latus* damages the leaves of a wide range of vegetables e.g. the African garden eggplant, aubergine, bean, cucumber, pepper, tomato and many other non-vegetable crops. The mite is an economically important pest of the African garden eggplant. Broad mites suck sap from leaves. On the African garden eggplant, the mite causes tiny pale spots to appear on leaves. Damage symptoms first appear on young leaves at the terminal growth points. In severe infestations, the leaves become narrow, tapering and yellowish (Figure 88). The mites rapidly reduce leaf area of the plant causing severe food and economic losses.

Method of spread: Being tiny and light, broad mites are easily blown by the wind from plant to plant.

Red mite, *Tetranychus* spp.

Recognition: Populations of *Tetranychus* species consist of eggs, nymphs and adults, all of which occur on the underside of leaves. Like all mites, red mites are wingless (Figure 89). The mites live on the underside of leaves and appear as tiny red specks to the naked eye. Young nymphs are light green, but mature nymphs are reddish like the adults. The presence of red mites is obvious by their damage symptoms on crops (Figure 90).

Biology: A female red mite lays up to 100 eggs in its life time. Red mites multiply rapidly and are mostly abundant in hot dry weather, especially if plants do not receive sufficient rain or irrigation water. The life cycle of the mite lasts for a little more than a week and the pest can produce several generations in a year. *Tetranychus* species produce webs of fine silk which protect them from certain predators and spray droplets of plant protection products. The common natural enemies of red mite are phytoseiids (predatory mites).

Economic importance: The red mite, *Tetranychus* spp., damages leaves of a wide range of vegetables e.g. the African garden eggplant, amaranth, aubergine, bean, cucumber, pepper, tomato and many other non-vegetable crops. The mite is an economically important pest of many vegetable crops. Nymphs and adults of red mites suck sap from the leaves, causing tiny pale spots to appear on leaves. Under severe attack, the leaves look reddish-brown in colour (Figure 90) and brittle as if they have been scorched by heat of the sun, and badly damaged leaves fall prematurely. The lack of, or untimely, irrigation worsens crop infestations by red mites and under such conditions the pest rapidly kills vegetable plants.

Method of spread: Red mites are easily blown by wind from plant to plant and from field to field. In this way, the mite infestation quickly spreads within vegetable plots. Transport of infested leaves is another major way of spreading the infestation.

Figure 89. The red mite, *Tetranychus* spp., on amaranth leaf. (Photo: G. Goergen/IITA)

Figure 90. Damage symptoms of the red mite, *Tetranychus* spp., on amaranth leaf. (Photo: B. James/IITA)

Figure 91. Cabbage heads damaged by the fungus *Sclerotinia sclerotiorum*. (Photo: B. James/IITA)

Pathogens

Fungus, *Sclerotinia sclerotiorum*

Recognition: The fungus *Sclerotinia sclerotiorum* occurs and reproduces on stem and the leaves of crops and weeds. The fungus in vegetables is recognised by its damage symptoms (Figure 91). It produces circular water-soaked areas on the foliage, the damaged areas later become covered by a fluffy white fungal growth. As the disease progresses, the damaged tissue becomes soft and watery. The fungus produces large, black, seed-like structures called sclerotia on diseased tissues.

Economic importance: *Sclerotinia sclerotiorum* damages leaves, stems and fruits of a wide range of vegetables crops e.g. aubergine, cabbage, cauliflower, bean, lettuce, okra, pepper, tomato and many other non-vegetable crops. The pathogen is a minor pest of the crops, usually of local importance. In cabbage, the fungus invades and destroys the entire cabbage head causing cabbage head rot (Figure 91).

Method of spread: Warm and damp weather favour the development and spread of *S. sclerotiorum*.

Fungus, *Colletotrichum capsici*

Recognition: The fungus *Colletotrichum capsici* occurs and reproduces on leaves, stems and fruits of crops and weeds. The presence of the fungus in vegetables is indicated by its damage symptoms. On leaves of the African garden eggplant, the fungus causes circular necrotic lesions that are white, surrounded by a brown colour (Figure 92). Severely affected leaves later become perforated as the dead tissues fall off. Additionally, the fungus causes rotting of the stems and wilting of the plant.

Figure 92. *Colletotrichum capsici* on African eggplant. (Photo: R. Sikirou/ INRAB)

Economic importance: *Colletotrichum capcisi* damages the leaves of a number of vegetables e.g. the African garden eggplant, onion, pepper, and tomato. This fungus is a minor pest of these crops, usually of local importance. Crop damage by the fungus is most prevalent in the rainy season. In severely infected fields, up to half of the leaves will show necrotic lesions.

Method of spread: *Colletotrichum capsici* is an air- and seed-borne pathogen. The fungus can survive in moist soil on decaying plant materials for several years. Compost and manure are therefore ideal sources of spread of the fungus. The fungus is also spread via infected soils on farm tools and footwear and by rain and irrigation water.

Figure 93. Leaf spots caused by the fungus *Cercospora* sp. on lettuce. (Photo: R. Sikirou/ INRAB)

Fungus, *Colletotrichum fuscum*

Recognition: The fungus *Colletotrichum fuscum* lives in the soil in the form of spores. The presence of the fungus in vegetables is indicated by its damage symptoms (similar to that shown in Figure 93). When in contact with leaves, spores of the fungus penetrate leaf tissue and develop into mycelia inside the plant. Damage symptoms of the fungus appear as light brown necrotic tissues spots on the leaves. Orange coloured area spreads around the spots (Figure 92). Severe infections cause leaf death.

Economic importance:The fungus *Colletotrichum fuscum* damages leaves of a number of vegetables e.g. the African garden eggplant, bean, lettuce and tomato. The pathogen is a minor pest of vegetables, usually of local importance.

Method of spread: The spores are dispersed by plant debris and farm tools contaminated by the spores and mycelia from infected soils, and by wind and rainwater.

Flower and fruit pests

Insects

Flower bud caterpillar, *Scrobipalpa ergasima*

Recognition: The flower bud caterpillar, *Scrobipalpa ergasima*, occurs on leaves, flowers and fruits of crop plants. The moth is small and light brown in colour and can be found on the underside of the leaves. The caterpillars are translucent with a black head and dark marks on the body. They are found mostly in flower buds and in developing fruits and exit holes on flower buds and developing fruits are a telltale sign of their presence (Figure 94).

Figure 94. African garden eggplant fruits and flower buds damaged by caterpillars of *Scrobipalpa ergasima*. (Photo: B. James/IITA)

Biology: Females of *S. ergasima* lay eggs in clusters (of up to six eggs per cluster) on very young flower buds. The eggs hatch into caterpillars within a week of being laid. Fully grown caterpillars leave the flower bud or developing fruit and drop to the ground to pupate. *Scrobipalpa ergasima* can produce three generations in a year. The caterpillars can be attacked by parasitoids e.g. *Apanteles*, *Bracon*, *Chelonus*, *Eriborus* and *Orgilus*, which also kill a number of other insects.

Figure 95. Flower bud caterpillars, *Scrobipalpa ergasima*, inside young fruits of the African garden eggplant. (Photo: B. James/IITA)

Economic importance: *Scrobipalpa ergasima* damages flowers and young fruits of the African garden eggplant and aubergine, and the insect is an economically important pest of these crops. The key damage is to flower buds, especially flower buds that are close to blooming. Young caterpillars tunnel into, eat, and destroy the interior of flower buds and developing fruits (Figure 95). The damage causes the bud to abort and no fruit (edible and marketable parts of the plant) will be formed. When the caterpillars leave the flower bud and drop to pupate in the ground, the exit holes will be the visible symptoms of damage the larvae would have caused. The part of a flower or developing fruit that joins the flower or fruit to stem branches is called the peduncle. Caterpillars of *S. ergasima* can penetrate peduncles and cause flowers and fruits to fall prematurely. Appendix 9 shows distribution of damage severity levels of the flower bud caterpillar on the African garden eggplant in Benin.

Method of spread: Moths of *S. ergasima* fly actively within and between fields.

Figure 96. Caterpillar of the cotton bollworm, *Helicoverpa armigera*. (Photo: G. Goergen/IITA)

Figure 97. Tomato fruit with damage holes caused by caterpillars of the cotton bollworm, *Helicoverpa armigera*. (Photo: B. James/IITA)

Cotton bollworm, *Helicoverpa armigera*

Recognition: Amongst vegetables, the cotton bollworm, *Helicoverpa armigera*, occurs mostly on flowers and fruits of tomato. Male moths are greenish-grey in colour while the females are orange-brown in colour. The forewings have blackish spots on the edges and a broad, brown band across the tail end of hind wings (Figure 16). Young caterpillars are yellowish-white to reddish-brown in colour. When fully grown, the caterpillars have two dark lines running along the length of their body (Figure 96).

Biology: Female moths of *H. armigera* lay eggs on leaves at the apex of plant shoots. The eggs hatch into caterpillars within a week and moult five to seven times before pupating. Mature caterpillars usually leave the plant and fall to the ground and pupate in the soil, but they can also pupate inside damaged fruits. During unfavourable conditions (e.g. hot dry weather conditions) the pupa can stay dormant for some time before hatching into an adult. *Helicoverpa armigera* is attacked by a wide range of natural enemies, especially parasitoids such as species of *Telenomus*, *Trichogramma* and *Trichogrammatoidea* which kill the eggs; other parasitoids kill the caterpillars.

Economic importance: Caterpillars of *H. armigera* damage leaves, flowers and fruits, and can defoliate entire plants. On tomato, young caterpillars feed on flowers and later bore into, and eat tomato fruits (Figure 97). The fruits rot later. A single caterpillar can destroy many tomato fruits before becoming a pupa. Appendix 9 shows distribution of damage severity levels of *H. armigera* on tomato in Benin.

Method of spread: Moths of *H. armigera* disperse by flying over long distances. Larvae rarely move from one plant to another. The pupa stage enables the pest to survive harsh conditions and to exploit food sources when these become available.

Fruit flies, e.g. *Dacus* spp.

Recognition: A number of fruit fly species damage vegetable fruits. Adult fruit flies are generally small with distinguishing body markings which differ according to the species of the insect. In *Dacus* species, the eyes are red and the front end of the body is dark orange to red-brown in colour, whilst the rear portion is black (Figure 98). The presence of puncture marks on fruits is usually indicative of fruit fly presence in the crop being inspected.

Figure 98. Adult female of the fruit fly *Dacus ciliatus*. (Photo: G. Goergen/IITA)

Biology: Females fruit flies lay eggs inside developing fruits, or near the surface of rotting foods or other moist, decaying vegetable matter. A female fruit fly lays about 500 eggs in its life time. The eggs hatch into larvae known as maggots which later pupate in the soil. The life cycle from egg, through larvae and pupae to adult is usually completed in about one week and the insect produces many generations in a year. Parasitoids are key natural enemies of the maggots and pupae of fruit flies.

Economic importance: Species of the fruit fly *Dacus* damage fruits of cucumber, watermelon, squash and tomato. The insect is economically important in vegetable production. Fruit flies damage crops in two ways. Firstly, females cause direct damage by puncturing the surface of fruits to lay eggs underneath fruit surfaces. In the process, the insect introduces bacteria which cause tissues of the fruits to rot. Fruit fly maggots prefer rotten tissues because they find it difficult to feed on fresh tissues of fruits. The combined action of the bacteria and feeding by the maggots causes the whole fruit to rot rapidly. Damaged fruits fall to the ground where the maggots pupate. All species of fruit flies are quarantine pests and cause indirect losses when importing countries reject and sometime destroy the damaged fruits.

Method of spread: Fruit flies are capable of flying long distances. The insects' spread is also encouraged by poor crop sanitation, e.g. leaving damaged fruits on the ground. Transporting infected fruits is another way fruit flies are distributed around the world.

Figure 99. Tomato leaves with damage symptoms of the tomato mite, *Aculops lycopersici*. (Photo: B. James/IITA)

Mites

Tomato mite, *Aculops lycopersici*

Recognition: The tomato mite, *Aculops lycopersici*, occurs on leaves, inflorescences and young fruits of tomato. The mites appear as red specks to the naked eye and are best seen under a hand lens or a binocular microscope. The appearance of shiny bronze shrivelled leaves (Figure 99) and fruits is indicative of the presence of the tomato mite.

Biology: The females lay eggs as soon as they colonize tomato plants. The mites develop from egg to adult in about a week, especially under dry weather conditions. Populations of the mite can therefore increase very rapidly on the crop. The common predators of the tomato mite are phytoseiids mites and hemipteran bugs e.g. *Agistemus exsertus* and *Euseius concordis*.

Economic importance: *Aculops lycopersici* damages leaves of aubergine, tomato and a few other non-vegetable host plants. The mite is an economically important pest of tomato attacking the crop at seedling, vegetative, flowering and fruiting growth stages of the plant. The mite sucks sap from the leaves, inflorescences and young fruits of tomato plants, and causes damaged leaves and fruits to turn shiny bronze in colour and become shrivelled up. Damaged flowers drop prematurely and under severe attack, damaged fruits become bronzed, hardened and unfit for food and sale. The pest damage to tomato is most severe during dry and hot weather which promotes rapid multiplication of the pest. The tomato mite can also transmit the fungal pathogen *Hirsutella thompsonii* to the plant.

Method of spread: The tomato mite is spread by wind.

Pathogens

Bacterium, *Xanthomonas campestris* pv. *vesicatoria*

Recognition: The bacterium *Xanthomonas campestris* pv. *vesicatoria* occurs on leaves, leaf petioles, stems, pedicels and fruits. In tomato, the first symptoms of the disease are small (about 3 mm in width) dark water-soaked circular spots (lesions) on the leaves which turn brownish-black and have a translucent centre. The lesions are usually numerous on young leaves. As the bacteria grow and damage the tissues, the lesions become angular. Infected fruits have small, black, raised specks on the fruit surface (Figure 100), the specks enlarge into brown and slightly sunken scabby spots, which may appear greasy and are sometimes surrounded by a whitish margin.

Figure 100. Tomato fruit with damage symptoms of the bacterium *Xanthomonas campestris* sp. (Photo: B. James/IITA)

Economic importance: The bacterium *Xanthomonas campestris* pv. *vesicatoria* damages leaves, stems, flowers and fruits of tomato and pepper. The bacterium is an economically important pest of tomato.

Method of spread: *Xanthomonas campestris* pv. *vesicatoria* is spread via crop debris, weeds and infected seeds. The bacterium is also spread by rain and irrigation by sprinkling.

Weeds


Figure 101. Spear grass, *Imperata cylindrica*. (Photo: B. James/IITA)


Figure 102. Bermuda grass, *Cynodon dactylon*. (Photo: B. James/IITA)


Figure 103. The sedge *Mariscus alternifolius.* (Photo: B. James/IITA)

Whenever an area is cleared for farming, weeds are among the first plants to grow on the land. Because they grow and reproduce very quickly, they can establish themselves on farms within a short time. Weeds grow more rapidly than other plants, occupying the spaces between crop plants and this enables them to 'choke' vegetables and shade them from sunlight. Weeds can cover the ground almost completely and increase the time farmers spend on weeding. When they are growing in abundance, weeds will use up a lot of nutrients and water from the soil, making these materials unavailable for vegetable plant growth. Certain plant pathogens, e.g. *Cercospora* sp. which damage amaranth, multiply on weeds which then serve as sources of the pathogens.

The main groups of weeds occurring in vegetable farms/ plots are:

- *Grasses:* Grasses are usually slender, erect, or creeping plants whose stems can be oval or cylindrical in shape. Leaves of grasses are much longer than they are broad and are never subdivided into little leaves (leaflets). Depending on locality and fallow status of the land, grass weeds which commonly cause problems in vegetable production include spear grass, *Imperata cylindrica* (Figure 101); Bermuda grass, *Cynodon dactylon*; (Figure 102) and Guinea grass.
- *Sedges:* Sedges resemble grasses but are always erect and usually have solid and triangular shaped stems. The sedge which causes problems in vegetable production is *Mariscus alternifolius* (Figure 103).

- *Broadleaf weeds:* Broadleaf weeds are herbs, creepers, climbers, and shrubs whose stems are solid and irregular in shape. Their leaves are broad, expanded, and single or subdivided into leaflets to form compound leaves. Broadleaf weeds of concern in vegetable production include the goat weed, *Ageratum conyzoides* (Figure 104) and tridax, *Tridax procumbens* (Figure 105).

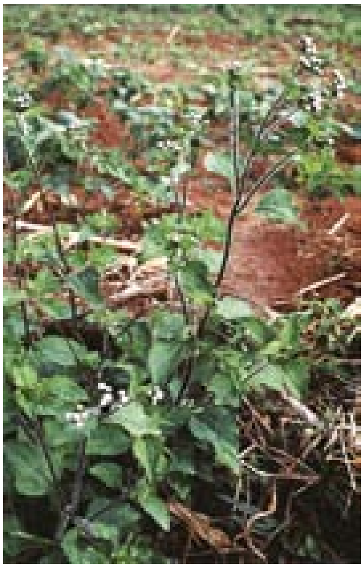


Figure 104. Goat weed, *Ageratum conyzoides.* (Photo: B. James/IITA)

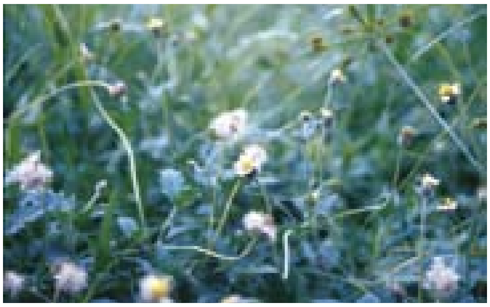


Figure 105. Tridax, *Tridax procumbens.* (Photo: B. James/IITA)

Figure 106. Rhizomes of spear grass, *Imperata cylindrica*. (Photo: B. James/IITA)

Figure 107. Tubers of the purple nut sedge, *Cyperus rotundus*. (Photo: B. James/IITA)

Figure 108. Farmer showing stolon length of Bermuda grass, *Cynodon dactylon*. (Photo: B. James/IITA)

Methods of weed spread

Weeds reproduce and spread through seeds and vegetative structures. Annual weeds reproduce and spread mainly by seeds and shed their seeds mostly in the dry season and die soon afterwards. The seeds survive in the soil and germinate the following season, or can remain in the soil for many years until disturbed when the soil is tilled for planting. The tridax daisy, *Tridax procumbens*, is an annual weed. Perennial weeds, on the other hand, persist for several years and are present at all seasons of the year. Some perennial weeds reproduce by seeds, whilst others reproduce by vegetative structures. Amongst vegetative reproductive structures are:

- *Rhizomes:* Rhizomes are underground stems running horizontal to the soil surface. They have thin brown papery leaves wrapped around the stem. The rhizomes have roots. Spear grass, *Imperata cylindrica* reproduces mainly by rhizomes (Figure 106).
- *Tubers:* Tubers are underground stems without leaves but with buds ('eyes'). The stems are swollen with stored food. Species of *Cyperus* and *Mariscus* spread by tubers. The tubers of *Cyperus* species occur as large 'beads' on underground slender stems which join the individual plants together (Figure 107).
- *Stolons:* A stolon is a slender stem that runs on the surface of the soil. Stolons have normal leaves and roots. The Bermuda grass, *Cynodon dactylon*, reproduces by stolons which are very long (Figure 108).

Weeds which reproduce by rhizomes, stolons and tubers are difficult to remove from the soil. They break easily into pieces during hand or hoe weeding. The pieces remain in the soil and later sprout and spread the weed. Farmers are therefore very likely to spread weeds which multiply by these vegetative reproductive structures during land and seed bed preparation. Weeds with these structures will therefore be 'stubborn' in vegetable farms. In addition to rhizomes, stolons and tubers, some weeds spread through other vegetative parts such as stem cuttings and basal shoot stocks.

IPM options

Biotic threats to vegetables are diverse and enormous. There can be, for example, up to eight economically important pests attacking a particular vegetable crop in a locality (Appendices 3 to 8). The pests disperse by active flight (e.g. moths), via air currents (e.g. mites), through planting materials (e.g. most pathogens), alternate host plants, contaminated farm tools and footwear (e.g. plant parasitic nematodes and plant pathogens), and by humans (through transport of planting materials). The objective of pest management is to minimize crop losses caused by pests with or without killing the organisms. There are various pest management options and these can be grouped into three broad categories: preventing physical access, environmental improvement, and population reduction (Box 5).

Integrated pest management (IPM) is a strategy that involves the combination of various crop protection options to avoid pest infestations from reaching economically damaging levels. IPM is carried out by farmers and not for farmers. In IPM, farmers combine options from research with traditional farming practices. Farmers need a full understanding of various pest management options in order to make informed choices on which combination of options are compatible in an IPM strategy. Extension workers also need this kind of information in order to empower farmers to identify IPM options that are best used at particular stages of plant production and crop growth. By incorporating IPM into plant production practices, farmers will be able to:

- Detect and nip pest problems in the bud and thereby provide long-lasting control of pests
- Promote vigorous and healthy growth of the crop
- Reduce pest problems and crop losses in a sustainable manner
- Prevent or reduce harm, injury to humans, livestock and the environment
- Increase the food and income value of the produce.

Pre-planting practices

Seed selection

Profitable vegetable farming hinges largely on the choice of quality seeds of varieties that are adapted to the environment where the crop would be grown. Self-supply of seeds from traditional vegetable varieties is a common farmers' practice. In order to assure seed quality and limit pest problems in the crops, it is advisable to:

- Avoid collecting seeds from plants whose inflorescences are infested with cocoons of moths, e.g. on amaranth, caterpillars of *Psara basalis* pupate in the inflorescence and the cocoons reduce the quality of seeds.
- Avoid collecting seeds from plants attacked by pathogens e.g. the fungi *Phytophtora* on amaranth, *Colletotrichum capcisi* on African garden eggplant, and bacteria such as *Xanthomonas vesicatoria* on tomato.

Box 5. Pest management options

Prevention of physical access

Pests can be prevented from gaining physical access to field crops by various kinds of barriers:

- Legislative control by governments or local authorities which pass and enforce laws or rules aimed at controlling pests that are of regional concern.
- Plant quarantine and the issue of international phytosanitary certificates are common legislative methods of pest control. The methods are particularly essential to prevent the introduction and spread of quarantine pests (especially alien invasive species) via planting materials.
- Physical barriers e.g. fencing of fields against ruminants; covering vegetable plots with nets against insect pests.
- Behavioural barriers e.g. use of pheromones to trap or repel insect pests.

Environmental improvement

- Environmental improvement is the creation of conditions through cultural control practices to discourage build-up of pests.
- In cultural control farmers manipulate existing agricultural practices consciously or unconsciously to provide plants with optimal conditions for growth, plant vigour and health and increased yields.
- Land preparation techniques, e.g., ploughing and minimum tillage.
- Use of resistant varieties to limit pest infestations and crop damage and increase yields.
- Adjustment of planting date to put vulnerable crop growth stages out of phase with the period of abundance of the damaging stages of pests.
- Intercropping to reduce pest infestations, increase soil health and suppress weeds.
- Crop sanitation by destruction or removal of badly diseased plants (roguing), badly damaged/diseased plant parts (pruning), crop residues and weeds which serve as sources of pests (especially plant pathogens) and carry-over populations of the pests.

Population reduction

- Population reduction methods primarily aim at killing pest organisms.
- Physical control methods which involve mechanical removal or destruction of pests, pest egg masses, diseases and weeds. The methods are labour intensive, expensive and require careful execution to achieve long-term success. Generally, physical control methods have limited use.
- Biological control by using natural enemies of pests.
- Chemical control (the use of pesticides to poison, repel or attract pests to baiting sites) reduces pest populations as a way of preventing injury to the crop.

- Buy certified seeds from reputable sources, such as seed companies or national seed services.
- Treat seeds with appropriate pesticides to prolong shelf life and protect emerging seedlings from damage by soil-borne organisms such as *Colletotrichum* spp., *Fusarium* spp. and *Pythium* spp. Contact the national plant protection services, national seed services, and seed companies for advice on availability of pesticides suitable for seed dressing.
- Field test seeds to verify their viability prior to planting: count 100 seeds, sow in three replications and note the number of healthy seedlings that sprout from the seeds.

Land and seed bed preparation

Good land, seedling nursery and seed bed preparation involve ploughing, harrowing, removal of plant debris and mulching prior to planting/sowing and transplanting vegetables on flat land or on 'beds'. These practices promote aeration, moistening and drainage of soils, enhance germination, encourage good root development, destroy weeds and their vegetative propagating structures, destroy dormant stages of insects, nematodes and pathogens, and reduce pest infestations. Land and seed bed preparation limit vegetable pest infestations in a number of ways, for example by:

- Breaking up and loosening the soil during ploughing and harrowing, which help to flush out adults and nymphs of the mole cricket *Gryllotalpa africana,* which live in deep tunnels and feed on plant roots and soil invertebrates.
- Cleaning seed beds to remove plant debris (roots, leaves and stems) with galls, lesions, streaks, cankers, leaf spots, shoot tip die-back which harbour plant parasitic nematodes and different kinds of pathogens. This helps to limit crop infection by pests carried over from the previous season.
- Mulching certain botanicals into seed beds can protect seedlings from damage by plant parasitic nematodes. Recent research shows that cassava epidermal peel or powder used as mulch in seed bed preparation reduces the incidence and damage symptoms of root-knot nematodes in seedlings of the African garden eggplant, carrot and tomato.
- Cleaning farm tools before and after tillage to reduce spread of soil-borne pests through use of contaminated farm tools.
- Complete removal of rhizomes, stolons, tubers and reproductive structures during land and seed bed preparation, to avoid germination of these structures which will aggravate weed problems.

Planting

Farmers commonly use intercropping and crop rotation to increase income per unit of land and labour. Close plant spacing and intercrops help to reduce weed infestations. Farmers learn through their own field experience the most compatible crops to intercrop and rotate and to identify appropriate planting dates. Vegetable planting dates are set in response to appropriate growing conditions (e.g. water availability for irrigation) and market demands for particular vegetables. In some cases, adjustment of the planting date enables farmers to avoid severe damage by pests. For example, the red mite *Tetranychus* spp. is abundant on amaranth during hot dry weather and in the absence of appropriate irrigation, dry season crops can quickly be lost due to attack by the mites.

Where crop rotation is adopted to avoid losses caused by plant-parasitic nematodes, knowledge of crop susceptibility to nematodes will be essential. Root-knot nematodes occur in most vegetable agroecosystems and infect a wide range of vegetable crops. In Benin, for example, the top five economically important vegetables are each attacked by at least three species of *Meloidogyne* identified on vegetables in certain localities of the country (Table 8). The wide host range of plant-parasitic nematodes makes it difficult to recommend effective crop rotation schemes, especially at sites under year-round vegetable production.

Table 8. Frequency of infection by root-knot nematode pests of vegetables in Benin.

Crops	Frequency of infection (%)				
	M. javanica	*M. incognita*	*M. exigua*	*M. arenaria*	*M. chitwoodi*
African garden eggplant	+++	+++	+	+	+
Amaranth	+	++	+	+	–
Cabbage	++	–	+	–	+
Lettuce	++	+	+	+	–
Tomato	+	++	+	–	+

Key: – = Not (yet) found on the crop, + = rare (less than 5% of the plants infected),
++ = Common (5–10% of plants infected), +++ = Most common (>10% of plants infected)

Post-planting

Sanitation/Physical control

Good farm sanitation and physical control are cultural practices that help to prevent pest infestations from causing economic damage. The practice is especially useful in small vegetable plots.

- Caterpillars of *Selepa docilis* clump together on a few leaves of the African garden eggplant and aubergine just after hatching. The leaves can be removed along with the caterpillars to prevent spread of the caterpillars to other leaves and plants.

- Caterpillars of *Psara basalis* and *Spoladea recurvalis* on amaranth and *Phycita melongenae* on the African garden eggplant live in distinct leaf shelters that are easily recognized. Timely removal of the leaf shelters halts the pests' spread within and between vegetable plants.
- When caterpillars of *Hellula undalis* damage terminal buds of cabbage, the plant compensates for damage by producing several multiple heads. Each of the multiple heads will be tiny and unfit for market and consumption. However, as soon the multiple heads are formed, farmers can remove the tiny heads leaving only one which could then grow into a larger and marketable cabbage head. Pruning of the tiny heads needs to be done early in the growth of the plant, if the practice is to produce marketable cabbage heads.
- If only a few seedlings sprout with a disease it is advisable to remove them. Bright yellow sticky traps attract certain insects, and can be used to indicate the presence of certain pests e.g. whiteflies and leaf miner flies.

Biological control

Biological control (or biocontrol) is a process by which man uses natural enemies to control pests. Biological control practitioners learn to monitor pests in agroecosystems and intervene early by introducing natural enemies well before pest populations grow to unacceptable levels. The general features of biological pest control are listed below (Box 6).

Box 6. General features of biological pest control

Natural enemies used in biological control are specific, in that they feed only on target pest organisms. They do not kill beneficial and harmless organisms in the agroecosystem. Also, they are not harmful to people and domestic animals.

Natural enemies are relatively slow acting, secretive in action, and lack the dramatic 'killing effects' associated with chemical control. Biological control therefore takes time to be established. However when fully established and left undisturbed, biological control is permanent, because the natural enemies are self-perpetuating and normally require no further intervention from man to ensure their continued success in controlling pests.

Natural enemies do not eradicate pest organisms, but act by reducing pest numbers to levels that cause little damage to the crop. Natural enemies are self-perpetuating, and will increase in numbers to control pests any time the pest population increases.

The number of natural enemies drops after they have reduced the number of pests. In this way the number of natural enemies and pest organisms fluctuates over time and pest infestations remain at levels that will not cause economic damage to the crop. Farmers should, therefore, always expect to see a few organisms of the pest that is controlled by biological control agents. If they do not understand the nature of biocontrol, farmers might revert to chemical control and inadvertently kill large numbers of natural enemies. This will enable the pest to increase in abundance resulting in severe damage.

Use of natural enemies in biological control is very easy and cheap for farmers. This is because biological control is either natural or developed by national or regional/international agricultural research institutions which serve communities through governments.

Biological control agents are used in pest management in three different ways:

Conservation biological control: In conservation biocontrol, action is taken to enhance the effectiveness of natural enemies already present in agroecosystem. This may involve planting flowering plants in order to attract natural enemies, providing suitable nesting sites for natural enemies, or reducing the amount of synthetic chemicals in a system to allow natural enemy numbers to increase. Conservation biocontrol involves intensive farmer education to increase their knowledge and understanding of the roles played by natural enemies and the effects of pesticides on the biological control agents. Conservation biocontrol is particularly useful to promote pest control of a wide range of parasitoids which attack aphids, diamond back moths, and leaf miner flies (Table 9), and phytoseiids which attack broad mite and red mites on the African garden eggplant and tomato.

Table 9. Parasitoids that benefit from reduced pesticide use in conservation biological control.

Crop	Pest	Parasitoids
African garden eggplant Bean Pepper	Aphid, *Aphis gossypii*	*Aphidius* spp.
Bean Lettuce Tomato	Leaf miner fly, *Liriomyza* spp.	*Chrysonotomyia* spp. *Halicoptera* spp. *Ganaspidium* spp. *Opius* spp.
Cabbage	Diamond back moth, *Plutella xylostella*	*Cotesia plutellae* *Diadromus collaris* *Oomyzus sokolowskii* *Microplitis plutellae*

Augmentation biocontrol is the addition of a parasitoid, predator or entomopathogen to an agroecosystem, either to boost existing numbers, or to start a new population of natural enemies that had previously disappeared. The term inoculation is used to refer to the practice in which small numbers of natural enemies are added and their abundance increases naturally over time (similar to the use of vaccines against diseases). If large numbers are added for rapid effect on the pest, this practice is called inundation. Applying large amounts of a fast-acting entomopathogen when a pest has reached economically damaging levels is a relatively easy approach that farmers familiar with chemicals can use against vegetable pests. Fast-acting microbial pesticides are particularly suitable for augmentation biocontrol against leaf-feeding pests of vegetables (Box 7).

Box 7. Potentially useful entomopathogens against vegetable pests in West Africa

Entomopathogen	Application
Bacterium, *Bacillus thuringiensis*	*Bacillus thuringiensis* occurs naturally in soils. Commercial biopesticides based on *B. thuringiensis*, or Bt, are available in different formulations. The active ingredients in Bt products are toxic protein crystals produced by the bacterium. Bt products are effective only if ingested by larvae and should therefore be applied to plants where larvae are present and actively feeding. When ingested, the toxic crystals damage the gut, usually leading to death of the insect within an hour to a few days. Unlike the active ingredients of other entomopathogens, the toxic crystal of Bt does not reproduce to continue the control effect. Also, after application, sunlight and rain can reduce the effectiveness of certain Bt formulations by deactivating and/or washing away the products. Bt products are therefore short-lived in field applications. Furthermore, pest resistance to Bt products can occur.
Fungus, *Beauveria bassiana*	The fungus *Beauveria bassiana* is is gaining attention as a commercial microbial pesticide as it is ubiquitous in nature, specific to target pests, persistent in the environment, and is easy to mass produce. Microbial pesticides based on *B. bassiana* are commercially available for use against leaf feeding caterpillars. In West Africa, microbial pesticides based on *B. bassiana* isolates from Benin are in development to control larvae of: diamond back moth, *Plutella xylostella* on cabbage, leaf caterpillars, *Psara basalis* and *Spoladea recurvalis* on amaranth, and cotton bollworm, *Helicoverpa armigera* on tomato. When spores of the fungus land on insects, they germinate, penetrate their bodies, grow inside and kill the insects within a few days. Unlike Bt products, fungal biopesticides do not need to be ingested in order to be effective against pests.
Viruses	The granulovirus PlxyGV-Nay01 is endemic to Kenya and in field trials it has proven to be effective against diamond back moth, *Plutella xylostella* on cabbage in East and West Africa.

Classical biological control is the importation of a natural enemy to a region where it has not previously been present and is usually appropriate against introduced pests. The interventions are mostly through inoculative releases of natural enemies, followed by post-release monitoring to see if they adapt, spread and establish on their own in the new region. Examples of successful classical biocontrol in vegetable production are rare in West Africa.

Classical biological control interventions require a great deal of research and international co-operation to:

- Scout for and collect natural enemies in the original habitat of the pest
- Screen collections in a quarantine laboratory to exclude unwanted organisms
- Import and field-test potentially useful natural enemies
- Multiply and release suitable natural enemies in the new region.

Use of botanicals: A major advantage of botanicals is that farmers can often self-supply the pesticide-providing plants from wild areas or by growing the plants in their neighbourhoods. West African farmers use neem tree leaf and seed extracts against a number of leaf-feeding caterpillars on a number of vegetable crops, e.g. the African garden eggplant, amaranth, aubergine, and cabbage. Recent research indicates that certain plant extracts have nematicidal properties e.g. cassava epidermal peeling or in powdered form. When applied as mulch in nurseries or at transplanting, the plant extracts boost vegetable plant health by protecting seedlings from plant-parasitic nematodes.

Semiochemicals are chemicals produced by insects and many other organisms to attract, repel, deter or stimulate some other particular behaviours or interactions between individuals.

Use of semiochemicals: There are two types of semiochemicals: pheromones which stimulate behaviour between individuals of the same species and allelochemicals which stimulate interactions between different species. Synthetic versions of insect sex pheromones, which are usually produced by females to attract males, are the most widely used in pheromone traps:

- To detect and monitor pests and thereby serve as an early warning device assisting farmers to implement control measures in a timely manner.
- Baited with a sticky surface or a synthetic pesticide to kill male insects attracted into it.
- Baited with a fungal biopesticide to infect male insects which fly off and spread the fungus to other individuals.
- Slowly released, and give a continual low concentration of the pheromone to disrupt mating by causing male insects to repeatedly attempt to mate without a female, or become 'used' to the pheromone so that they no longer respond to the attractant.

Chemical control

Chemical control refers to the application of pesticides to kill, repel or reduce pest populations as a means to prevent injury to crops, animals and humans. Pesticides are common IPM options in vegetable production, mainly because the products are quick-acting and cause rapid and high mortality in the pest populations. Pesticides are also excellent for remedial or curative action, e.g. when pest infestations and/or crop damage levels exceeds acceptable levels, or under emergency situations such as pest outbreaks.

Agricultural extension workers and farmers should, be aware that most pesticides are generally designed to kill a wide variety of pests (i.e. have broad spectrum toxicity) and will be harmful to natural enemies, the environment, livestock and humans. A few pesticides are designed to kill a very narrow range of pests (selective pesticides). With broad spectrum toxicity, one pesticide type can be used against different types of pests. If broad spectrum pesticides are not used selectively, the pesticides will pose risks to non-target organisms. Another concern to be aware of in chemical control is that pesticides contaminate vegetables and thereby undermine trade in the produce.

Agricultural extension workers and farmers must fully understand that in IPM, chemical control interventions should always be guided by:

- Correct identification of the pest on the crop and its growth stage at the time of the interventions
- Periodic monitoring to correctly assess the severity of crop damage caused by the pest
- The type of pesticide to be used
- Consideration of non-chemical control alternatives
- Compatibility of the pesticide with biocontrol interventions that are established in the field.

A **nematicide** is a type of pesticide used to kill parasitic nematodes.

Training courses on the safe use of pesticides are recommended. They cover guiding principles for pesticide handling and applications so as to enable users to obtain effective results, while safeguarding life and the environment.

Learning IPM

IPM success depends largely on farmers' knowledge and understanding of pests, biological and ecological processes that affect pests, and on how well they use that knowledge in the choice of IPM options. Knowledge and understanding of which options to use and at which crop growth stages to use the options, are critical to IPM success. Participatory learning approaches promote effective communication between extension workers and farmers, encourage 'learning by doing' in IPM, and promote informed decision-making by farmers on how to solve vegetable pest problems.

Farmer participatory learning processes enable participants to:

- Increase their knowledge and understanding of biodiversity associated with vegetables.
- Adopt regular field monitoring for timely detection of changes in pest status.
- Increase their understanding of ecological and socioeconomic aspects of pest problems.
- Critically assess and adapt traditional, new knowledge and IPM options.
- Promote hands-on learning of crop and pest management techniques and skills.
- Select, adapt, combine and apply IPM options as integral components of vegetable production.
- Facilitate IPM learning and informed decision-making by colleagues.
- Promote wider adoption of IPM.

Farmer participatory learning processes make IPM easy to understand, apply and use at farm level. The farmer field school (FFS) is a common experiential learning model (Figure 109) for IPM in West African agriculture. Small groups of farmers and extension workers learn to integrate scientific information and technologies with

Figure 109. Vegetable field plot study by farmers. (Photo: C. Atcha-Ahowé/IITA)

traditional farming practices. Ideally, training participants are representatives of a subset of farmers whom they would interact with frequently. Training participants should also be willing to share with other farmers the knowledge and skills they themselves would have learned and adopted.

The key features of FFS are as follows:

Baseline surveys: Baseline surveys aim to summarise profiles of proposed sites/crops for which training is planned, and provide an overview of the situation that needs to be improved. The chapter on field diagnosis presents focus group interviews and field inspections as examples of methods used to develop the site profiles and overviews pest problems. Appendices 1 and 2 summarise the results of focus group interviews from a peri-urban vegetable production site in Benin.

Curriculum development: Curriculum development is best achieved by a team of scientists, trainers/training facilitators, extension agents and farmers' representatives. Together the team will analyse the baseline survey data and identify constraints/ issues and opportunities/options to include in the curriculum. FFS curricula for IPM usually include aspects of land preparation, soil health, nursery management, crop growth, nutrient management, pest and natural enemy identification, integrating options, non-formal education; computer skills and report writing and an economic analysis of IPM. At frequent intervals (weekly for vegetables), the training curriculum is delivered through group presentations and hands-on field plot experiments.

Farmers' experiments: IPM farmer study groups are small, usually consisting of a little over two dozen farmers. Through their own participatory research, farmers contribute to researchers' efforts to develop IPM options. Sub-groups of participants carry out field trials to test and validate IPM options and ensure that options offered in the curriculum are technically, practically and socio-economically feasible. The research results feed into learning sessions for farmer study groups to understand the principles and practices of IPM in the crop. Promising vegetable IPM options which need farmer participatory validation in West African countries include:

- Isolates of the entomopathogenic fungus, *Beauveria bassiana*, for use against diamond back moth, *Plutella xylostella*, on cabbage, leaf caterpillars, *Psara basalis* and *Spoladea recurvalis*, on amaranth, and cotton bollworm, *Helicoverpa armigera*, on tomato
- The granulovirus PlxyGV-Nay01 (from Kenya) for use against diamond back moth on cabbage
- Efficacy of commercial formulations of *Bacillus thuringiensis* against leaf feeding caterpillars
- Botanicals for use against root-knot nematodes, *Meloidogyne* spp., which damage a wide range of vegetables
- Reduced pesticide use to promote conservation biocontrol of leaf miner flies, *Liriomyza* spp., on bean, lettuce and tomato, and diamond back moth on cabbage.

Data processing and presentation: This is a detailed analyses (called an agroecosystem analysis [AESA]) based on sub-groups of data from field observations and results from farmers' experiments (Figure 110). Presentations of AESA and experimental results of participants will be followed by a discussion (questions, answers, comments, suggestions and corrections) before they are accepted by the FFS group as the training output of the day. Table 10 shows an example of a presentation summarizing AESA results from a peri-urban site in Benin. AESA data sheets normally include illustrations/drawings by farmers to depict their observations in the field. During training, trainers can identify participants as potential community organizers to promote dissemination of IPM practices in their localities. They can spread information about IPM in a number of ways: farm visits, community demonstration plots and field days, focus group talks, public awareness campaigns, farmer-to-farmer networking, and information resource mobilization. This would help increase the adoption and wider spread of IPM practices in communities, as well as enhance community self-reliance in addressing current and emerging pest problems in vegetable production.

Special topics: After AESA presentations, topics of special concern to farmers will be identified and resource persons will be invited to give talks on these topics in the following training session.

Figure 110. Small group analyses of field plot study data. (Photo: C. Atcha-Ahowé/IITA)

Table 10. Example of a presentation summarizing AESA results

1. General information
Weather: Sunny *Crop:* Cabbage *Variety:* K.K. Cross *Weeks after transplanting:* 4 *Growth stage:* Pre-capping
2. Agronomic information
Average plant height: 13.2 cm *Average number of leaves:* 18.4 *Average canopy diameter:* 29.4 mm *Soil moisture:* Medium *Pesticide application:* 3 to 4 day intervals
3. Pests/diseases
DBM larvae: average of 20 per plant *Leaf miners:* a few tunnels on the plants
4. Natural enemies
Predators: 4 Coccinellid adults *Parasitoids:* 3 mummies *Entomopathogens:* None
5. Observation
85% leaf damage 10% leaf mining 13% leaf scorch Low number of natural enemies
6. Suggested causes
Monocropping Late planting Lack of food for wasps Chemical pesticide use kills natural enemies
7. Recommendation by group
Use botanicals or biopesticides Plant yellow flowering plants to attract adult parasitoids and serve as food source for the parasitoids Companion planting: plant garlic or onion to repel moths Reduce use of chemical pesticides

Conclusion

Farmers make crop production management decisions based on issues such as yield, palatability and market potential, and often omit crop protection as a consideration. Planting dates are chosen mainly on the basis of a socio-economic calendar of activities. Agronomic techniques are largely dictated by labour and economic realities at the time. Some of these decisions may affect the type of IPM options which are used in current or subsequent crops. This guide aims to equip extension workers with the knowledge and skills required for them to assist farmers to maximise the production and protection of their vegetable crops and to use available IPM options effectively.

Agroecosystems as functional units: The techniques outlined in this guide promote inter-disciplinary collaboration that will help extension workers to increase their knowledge and understanding of IPM. At the same time, extension workers as members of a multidisciplinary team must realise that while they can learn particular skills, they cannot be specialist entomologists, pathologists, weed scientists or agronomists. Increased knowledge of the components of vegetable agroecosystems and of the interactions between, and within, these components help extension workers to treat the agroecosystem (farm) as a single functional unit. Extension workers armed with a holistic view can offer better advice on the choice and application of IPM options in ways that will promote vegetable plant health, while also protecting man and the environment. By understanding and treating vegetable agroecosystems as functional units, extension workers and farmers will learn that a pest-free plot of vegetables does not always mean an increase in income; it may sometimes lead to a decrease in profits.

Field monitoring: All the pests listed in this guide are unlikely to occur in the same field and at the same time. Vegetable pest problems are however very dynamic. The infestations change dramatically over short time periods, especially in the dry season when hot dry weather promotes rapid build-up of insect and mite pest populations. New pests may appear suddenly and spread quickly in the agroecosystem, sometimes in an unpredictable manner. Inappropriate agronomic practices, chemical pest control methods, and climate change effects can elevate pests from minor status to economically important status. Frequent farm visits are therefore essential to note and respond rapidly to these kinds of changes in a timely manner. During field monitoring visits, extension workers should always check for other (unreported) problems which are likely to occur at the stage of growth and/or during cropping seasons.

Pest lists: Pest lists are essential in international trade in vegetables. The field diagnostic methods and specimen collection techniques presented in this guide aim to increase the capacity of extension workers to correctly identify and assess the economic importance of pests. Extension workers should be encouraged to collate their observations into comprehensive pest lists and reference collections of specimens. Pest lists (indicating associated biodiversity in the locality) are essential baseline resources to inform governments and stakeholder groups on economic risks associated with international transfer of vegetable materials. Pest lists and reference collections are also useful resources for extension workers to cross-check and advise on changes in the incidence and diversity of pests in vegetable agroecosystems.

IPM promotion: Harmful effects of inappropriate chemical control methods underline the need to search for and promote biologically-based IPM options in vegetable production. In their work to introduce farming communities to ecologically sound solutions to pest problems, extension workers need a full understanding of the types, nature and mode of operation of available IPM options. Extension workers also need to be aware that IPM applications can have unintended benefits as well as conflicting effects. Through experiential learning, extension workers can assist vegetable farmers to identify farm practices that have more than one intended effect, and increase community awareness on their findings.

Appendices

Appendix1: Vegetable site profile – summary results of focus group interviews, Cotonou, Benin

Parameter	Farmers' collective response
Total land area	Potential = 3.5 ha In use = 2.5 ha
Land holding per farmer	35 Beds @ 1.2 m x 7 m [= 294 m^2]
Major crops	Ranked in descending order of importance in terms of area under cultivation: African garden eggplant > Amaranth > Cabbage > Lettuce > Tomato
Major problems reported by farmers	*African garden eggplant:* Yellowing and tapering of leaves *Amaranth:* Lack of manure; leaf damage by caterpillars *Cabbage:* Leaf damage by diamond back moth and aphids *Lettuce:* Leaf diseases; leaf miners *Tomato:* Yellowing of leaves; flower abortion
Popular intercrops	*African garden eggplant:* Amaranth; lettuce; *Vernonia* *Amaranth:* African garden eggplant; lettuce; *Vernonia* *Cabbage:* Lettuce; carrot *Lettuce:* African garden eggplant; cabbage; *Vernonia*; amaranth *Tomato:* Okra
Popular crop rotations	*Amaranth:* African garden eggplant; cabbage; carrot; lettuce; tomato *Cabbage:* Amaranth; carrot; lettuce; tomato *Lettuce:* African garden eggplant; amaranth; cabbage; tomato *Tomato:* African garden eggplant; amaranth; carrot; lettuce; onion; pepper; tomato
Source of water	Dug-outs or wells
Mode of irrigation	Watering cans (farmer usually carries two cans at a time) Water fetched from the dug-outs/wells Powered irrigation/water pumping machine with attached hose
Fertilizer application	*Chemical:* NPK and urea *Organic:* Farmyard manure, e.g. poultry, rabbit, pig manure Household organic manure (remove plastics, cans, bottles) Brewery waste (cereal husks, etc.) Cow dung is not used because farmers observe that it attracts insect pests
Pesticide application	*Chemical pesticides:* Acephate; Bifenthrin; Chlorpyrifos ethyl; Cyfluthrine + Malathion; Cypermethrin + phoslane Deltamethrin; Dicofol; Dimethoate; Fenpropathrin; Glyphosate; Maneb; Methamidophos; Profénofos; Thiophanatemethyl *Botanical pesticides:* Neem leaf extracts; neem seed oil; neem seed cake *Biopesticides:* None

Appendix 2: Economics of vegetable production – a format for use in focus group interviews

Item	FCFA per area (specify area in hectares)			
	Sole crop of cabbage		Cabbage/amaranth intercrop	
	Low price	High price	Low price	High price
1. Gross return per unit (e.g. bed)				
Cabbage price	0,000	0,000	0,000	0,000
Cabbage return	000,000	000,000	000,000	000,000
Amaranth price	Not applicable	Not applicable	0,000	0,000
Amaranth return	Not applicable	Not applicable	000,000	000,000
SUB-TOTAL	**000,000**	**000,000**	**000,000**	**000,000**
2. Material inputs for total area				
Land	0,000	0,000	0,000	0,000
Cabbage seed	0,000	0,000	0,000	0,000
Amaranth seed	Not applicable	Not applicable	0,000	0,000
Chemical fertilizer [NPK + urea]	0,000	0,000	0,000	0,000
Organic manure	0,000	0,000	0,000	0,000
Chemical pesticides	00,000	00,000	00,000	00,000
SUB-TOTAL	**00,000**	**00,000**	**00,000**	**00,000**
3. Labour inputs for total area				
Nursery management	0,000	0,000	0,000	0,000
Pesticide application	0,000	0,000	0,000	0,000
Fertilizer application	0,000	0,000	0,000	0,000
Weeding/other chores	0,000	0,000	0,000	0,000
Irrigation	00,000	00,000	00,000	00,000
SUB-TOTAL	**00,000**	**00,000**	**00,000**	**00,000**
4. Other inputs/Association fee	0,000	0,000	0,000	0,000
5. Grand total inputs [i.e. #2+#3+#4]	00,000	00,000	00,000	00,000
6. Net returns/35 beds or per 0.03ha [i.e. #1 less #5]	000,000	000,000	000,000	000,000
7. Net returns/ha	00,000,000	00,000,000	00,000,000	00,000,000
8. Benefit–cost ratio [i.e. #1/#5]	0.00	0.00	0.00	0.00

Appendix 3: Pests of the African garden eggplant in Benin

Type of pest	Species	Plant parts attacked	Level of damage	Sources of infestation: Other vegetable crops attacked	Sources of infestation: Other crops and plants attacked
Insects	*Helopeltis schoutedeni*	Leaves	High		Annatto; cashew nut; cassava; castor bean; cotton; tea
	Phycita melongenae	Leaves	High	Aubergine; okra	
	Scrobipalpa ergasima	Flowers; fruits	High	Aubergine	
	Selepa docilis	Leaves	High	Aubergine	
	Aspavia armigera	Leaves	Low	Cabbage; carrot; lettuce	Rice
	Bemisia tabaci	Leaves	Low	Aubergine; cucumber; lettuce; okra; pepper; tomato	Bean; cassava; sweet potato; cotton; tobacco; poinsettia
	Cassida sp.	Leaves	Low	Amaranth	
	Epilachna elaterii	Leaves	Low	Cucumber; lettuce; melon; pumpkin	
	Nezara viridula		Low	Amaranth; cabbage; okra; tomato	Peas
	Liriomyza spp.	Leaves	Low	Amaranth; cabbage; cucumber; lettuce; tomato	
Mites	*Polyphagotarsonemus latus*	Leaves	High	Aubergine; bean; cucumber; cruciferous crops; pepper; tomato	Avocado; cotton; lemon; mango; papaw; potato
	Tetranychus spp.	Leaves	High	Amaranth; bean; cucurbits; pepper; radish; tomato	Cassava; cotton
Pathogens	*Fusarium* spp.	Leaves	High	Amaranth; lettuce	
	Sclerotium spp.	Roots		Bean; lettuce; tomato	
Nematodes	*Meloidogyne* spp.	Roots	High	Wide range of vegetables	Wide range of other crops and plants
	Other plant parasitic nematodes		Low	Wide range of vegetables	Wide range of other crops and plants

Appendix 4: Pests of amaranth in Benin

Type of pest	Species	Plant parts attacked	Level of damage	Sources of infestation: Other vegetable crops attacked	Sources of infestation: Other crops and plants attacked
Insects	*Psara basalis*	Leaves	High	Quail grass	Citrus; rice
	Spoladea recurvalis	Leaves	High	Radish; beetroot; carrot; cucurbits	Cotton; maize; soybean
	Aspavia armigera		Low	African garden eggplant; cabbage; carrot; lettuce	Rice
	Epilachna elaterii		Low	African garden eggplant; cucumber; lettuce; melon; pumpkin	Wild cucurbits
	Gasteroclisus rhomboidalis	Roots; stems	Low		
	Hypolixus nubilosis	Roots; stems	Low	Cabbage; cucumber; lettuce	
	Liriomyza spp.	Leaves	Low	African garden eggplant; cabbage; cucumber; lettuce; tomato	
	Nezara viridula		Low	African eggplant; cabbage; okra; tomato	Peas
Mites	*Tetranychus urticae*	Leaves	Low	Legumes; tomato; beans; cucurbits; peppers; radish	Cassava; cotton
	Polyphagotarsonemus latus	Leaves	Low	African garden eggplant; aubergine; bean; cucumber; cruciferous crops; pepper; tomato	Avocado; cotton; lemon; mango; pawpaw
Pathogens	*Alternaria* spp.		Low	Broccoli; carrot; cauliflower; tomato	Potato; citrus; apple
	Fusarium spp.		Low	African garden eggplant; lettuce	
Nematodes	*Meloidogyne* spp.	Roots	High	Wide range of vegetables	Wide range of other crops and plants
	Other plant parasitic nematodes	Roots	Low	Wide range of vegetables	Wide range of other crops and plants

Appendix 5: Pests of cabbage in Benin

Type of pest	Species	Plant parts attacked	Level of damage	Sources of infestation: Other vegetable crops attacked	Sources of infestation: Other crops and plants attacked
Insects	*Hellula undalis*	Leaves	High	Broccoli; cauliflower; other cabbages; radish	
	Lipaphis erysimi	Leaves	High	Aubergine; other cruciferous crops; radish; rape; turnip	Siam weed
	Plutella xylostella	Leaves	High	Aubergine; black mustard; broccoli; kale; radish; turnip; watercress	
	Acrosternum acutum	Leaves	Low	African garden eggplant; amaranth; okra; peas; tomato	
	Epilachna elaterii	Leaves	Low	African garden eggplant; amaranth; cucumber; lettuce; melon; pumpkin	
	Hypolixus nubilosis	Leaves and stems	Low	Cucumber; lettuce	
	Liriomyza spp.	Leaves	Low	African garden eggplant; amaranth; cucumber; lettuce; tomato	
	Nezara viridula	Leaves	Low	African garden eggplant; amaranth; okra; peas; tomato	
Mites	*Polyphagotarsonemus latus*	Leaves	Low	African garden eggplant; amaranth; tomato	
Pathogens	*Colletotrichum higginsianum*		Low	Cruciferous crops	
	Xanthomonas campestris pv. *campestris*		Low	Broccoli; cabbages; cauliflower; kale; radish	
Nematodes	Root-knot nematodes, *Meloidogyne* spp.	Roots	Low	Wide range of vegetables	Wide range of other crops and plants
	Other plant parasitic nematodes	Roots	Low	Wide range of vegetables	Wide range of other crops and plants

Appendix 6: Pests of lettuce in Benin

Type of pest	Species	Plant parts attacked	Level of damage	Sources of infestation: Other vegetable crops attacked	Sources of infestation: Other crops and plants attacked
Insects	*Liriomyza* spp.	Leaves	Low	African garden eggplant; amaranth; cabbage; cucumber; lettuce; tomato	
	Hypolixus nubilosis	Roots	Low	Cabbage; cucumber	
Mites	None found on lettuce				
Pathogens	*Colletotrichum fuscum*	Leaves	High	African garden eggplant; green bean; tomato	
	Fusarium spp.	Leaves	Low	Amaranth; African garden eggplant	
	Sclerotium spp.	Roots	Low		
Nematodes	*Meloidogyne* spp.	Roots	High	Wide range of vegetables	Wide range of other crops and plants
	Other plant parasitic nematodes		Low	Wide range of vegetables	Wide range of other crops and plants

Appendix 7: Pests of tomato in Benin

Type of pest	Species	Plant parts attacked	Level of damage	Sources of infestation: Other vegetable crops attacked	Sources of infestation: Other crops and plants attacked
Insects	*Bemisia tabaci*	Leaves	High	African garden eggplant; aubergine; bean; cruciferous crops; cucumber; cucurbits lettuce; okra; pepper	A wide range of other crops and plants
	Helicoverpa armigera	Fruits; Flowers;	High	Amaranth, cabbage; lettuce; okra; onion; Solanum species	
	Liriomyza spp.	Leaves	Low	African garden eggplant; amaranth; cabbage; cucumber; lettuce; tomato;	
	Nezara viridula	Leaves	Low	African garden eggplant; amaranth; cabbage; okra; peas	
Mites	*Aculops lycopersici*	Leaves	High	Aubergine	Sweet potato; tobacco
	Polyphagotarsonemus latus	Leaves	Low	African garden eggplant; amaranth; tomato	Wide range of other crops and plants
Pathogens	*Phytophtora* spp.		Low	African garden eggplant; many other vegetables; pepper	
	Sclerotium spp.		Low	African garden eggplant; bean; lettuce;	
Nematodes	*Meloidogyne* spp.	Roots	High	Wide range of vegetables	Wide range of other crops and plants
	Other plant parasitic nematodes	Roots	Low	Wide range of vegetables	Wide range of other crops and plants

Appendix 8: Pests of vegetables in Benin

Pest species	African garden eggplant	Amaranth	Cabbage	Lettuce	Tomato
Root/soil-borne pests					
Insects					
Beetle, *Gasteroclisus rhomboidalis* (Coleoptera: Curculionidae)		●			
Gryllotalpa africana	●	●	●	●	●
Plant parasitic nematodes					
Meloidogyne sp. (root-knot nematode)	■	●	●	■	■
Other nematodes	●	●	●	●	●
Pathogens					
Bacterium, *Erwinia carotovora*					
Bacterium, *Ralstonia solanacearum*					
Bacterium, *Xanthomonas campestris* pv. *campestris*			■		
Fungus, *Fusarium oxysporum* f. sp. *lycopersici*	■	●		■	
Fungus, *Phytophtora* spp.					●
Fungus, *Sclerotium rolfsii*	●			●	●
Leaf/stem feeders					
Insects					
Acrosternum acutum (Hemiptera: Pentatomidae)			●		
Anoplocnemis curvipes (Hemiptera: Coreidae)		●		●	
Aspavia armigera (Hemiptera: Pentatomidae)	●	●	●	●	
Whitefly, *Bemisia tabaci* (Hemiptera: Aleurodidae)	●				■
Cassida sp. (Coleoptera: Chrysomelidae)	●				
Earias biplaga (Lepidoptera: Noctuidae)				●	
Ladybird, *Epilachna elaterii* (Coleoptera: Coccinellidae)	●	●	●		
Cabbage webworm, *Hellula undalis* (Lepidoptera: Pyralidae)			●		
Plant bug, *Helopeltis schoutedeni* (Hemiptera: Miridae)	■				

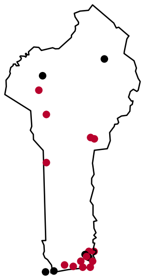
Pest species	African garden eggplant	Amaranth	Cabbage	Lettuce	Tomato
Weevil, *Hypolixus nubilosus* (Coleoptera: Curculionidae)		●	●	●	
False cabbage aphid, *Lipaphis erysimi* (Homoptera: Aphididae)			■		
Liriomyza sp. (Diptera: Agromyzidae)	●	●	●	●	●
Green stink bug, *Nezara viridula* (Hemiptera: Pentatomidae)		●	●		
Leaf caterpillar, *Phycita melogenae* (Lepidoptera: Pyralidae)	■				
Diamond back moth, *Plutella xylostella* (Lepidoptera: Plutellidae)			■		
Leaf caterpillar, *Psara basalis* (Lepidoptera: Pyralidae)		■			
Leaf caterpillar, *Selepa docilis* (Lepidoptera: Noctuidae)	■				
Beet webworm, *Hellula undalis* (Lepidoptera: Pyralidae)		■			
Mites					
Polyphagotarsonemus latus (Acari: Tarsonemidae)	■	●	●		●
Tetranychus spp. (Acari: Tetranychidae)	●	■			
Pathogens					
Fungus, *Sclerotiniasderotiorum*	●			●	●
Fungus, *Colletotrichum capsici*			■		
Fungus, *Colletotrichum fuscum*				■	
Flower/fruit feeders					
Insects					
Dacus spp. (Diptera: Tephritidae)			●		
Helicoverpa armigera (Lepidoptera: Noctuidae)					■
Scrobipalpa ergasima (Lepidoptera: Gelechiidae)	■				
Mites					
Aculops lycopersici (Acari: Eriophyidae)					■
Pathogens					
Xanthomonas campestris pv. *campestris*			■		

Key:

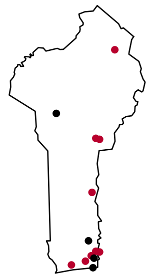
■ = Economically important pests (caused moderate to severe damage in more than 10% of plants sampled)

● = Minor pests (caused moderate to severe damage in less than 10% of plants sampled)

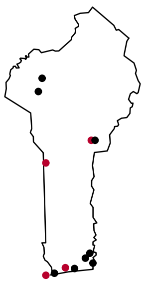
Appendix 9: Distribution of pests of vegetables in Benin



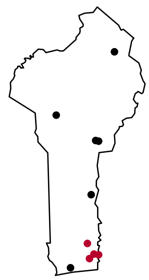
Distribution of damage severity caused by root-knot nematode on the African eggplant.



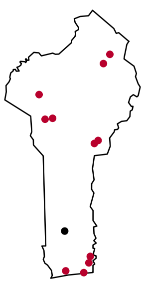
Distribution of damage severity caused by *Spoladea recurvalis* on amaranth.



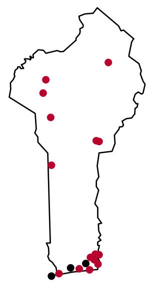
Distribution of damage severity caused by *Selepa docilis* on the African eggplant.



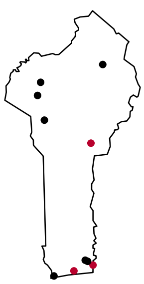
Distribution of damage severity caused by *Psara basalis* on amaranth.



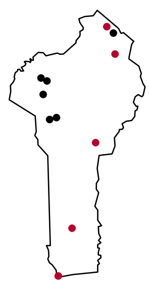
Distribution of damage severity caused by diamond back moth , *Plutella xylostella*, on cabbage.



Distribution of damage severity caused by the broad mite, *Polyphagotarsonemus latus*, on the African eggplant.



Distribution of damage severity caused by *Scrobipalpa ergasima* on the African garden eggplant.



Distribution of damage severity caused by the cotton bollworm, *Helicoverpa armigera*, on tomato.

Legend: ● low damage
● high damage

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Note: page numbers in *italics* refer to figures and tables, those in **bold** refer to boxes and margin notes

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A collaborative effort of various authors, this well-illustrated guide addresses a major gap in knowledge on sustainable production and plant protection in horticultural systems. Primarily intended for field practitioners and extension workers, it is also useful for technicians, students and scientists. Besides providing practical knowledge on how to sustainably manage biotic threats to healthy vegetable production, the guide has useful suggestions on how to teach and disseminate IPM practices to a larger audience.

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