FEED THE FUTURE INNOVATION LAB FOR INTEGRATED PEST MANAGEMENT PRESENTS THE 2021:

IPM PACKAGES FOR TROPICAL CROPS
For nearly 30 years, the Feed the Future Innovation Lab for Integrated Pest Management (IPM Innovation Lab) has been implementing integrated pest management practices around the world. IPM is an environmentally-sensitive approach to crop management that relies on a combination of common-sense farming practices. One of the IPM Innovation Lab’s most successful and long-standing initiatives is development of the IPM Package. Given the range of conditions, resources, and skills available in any community, farmers must find crop production strategies that not only produce positive results, but fit seamlessly into their lives. The IPM Package can help them achieve this.

IPM Packages outline insect pests, diseases, and threats that a crop faces, and offers IPM techniques that can be used to combat those threats. IPM Packages are seldom applied in full, but farmers select individual technologies when needed. The packages are designed so that technologies can be adopted in a targeted location for a specific pest complex. Farmers who have implemented IPM Package components while planting, growing, and harvesting, and throughout the supply chain, have observed enhanced yields, increased income, reduced reliance on chemical pesticides, and overall profitability.

As globalization increases, environments are changing. Invasive species spread continues to impact native growth, while erratic weather conditions change the way systems operate. With that, farmers – especially those working within resource-constrained communities – must be prepared to address the current and emerging threats to their fields without compromising their health, production, or economic well-being.

“It’s important to remember,” said Muni Muniappan, Director of the IPM Innovation Lab, “that the work we do to protect our crops, farmers, and livelihoods in one country can benefit the entire world. IPM Packages meet farmers where they are and prepare them for surpassing crop production demands of the future.”

Over the last three decades, the IPM Innovation Lab - funded by the U.S. Agency for International Development and housed at Virginia Tech’s Center for International Research, Education, and Development - has worked in West and East Africa; Eastern Europe; Central, South, and Southeast Asia; and Latin America and the Caribbean. This booklet outlines some of the major crops grown in many of those countries, the threats those crops face, and the IPM Packages that can be used to address them.
Dear readers,

Since the inception of Integrated Pest Management, several iterations of the concept have been explored; however, the core focus has been the same – to develop and apply safe, effective, socially acceptable, and economically viable technologies to manage plant pests.

The IPM Collaborative Research Support Program (IPM CRSP), later named the IPM Innovation Lab, aims to do just this. The program has worked in over 30 different countries around the world on a range of crops including vegetables, cereals, legumes, and fruits. Taking a holistic approach, the program addresses problems faced by farmers from the time of planting seeds to harvest by developing and promoting alternate technologies to toxic synthetic chemical pesticides. These technologies are grouped into an ‘IPM Package’ and disseminated to farmers in developing countries. When no alternate technologies are available, the program recommends the use of safe synthetic chemical pesticides. In addition to developing IPM Packages for crops, the IPM Innovation Lab works among a number of other interrelated cutting-edge scientific areas, such as modeling and management of the invasive species *Parthenium hysterophorus* and papaya mealybug *Paracoccus marginatus*, and monitoring the impacts of climate change on biodiversity.

The strength of the IPM Innovation Lab’s approach is adaptability. Between 720 and 811 million people in the world faced hunger in the year 2020. Globally, farmers stand to lose nearly half of their crop yields to plant pests. To ensure that we do not further burden already resource-limited farmers around the world, we must help them adapt to ever-evolving climate, economic, and environmental conditions. Beyond presenting IPM Packages that target farmers’ greatest pest problems, we collaborate with local institutions, scientists, graduate students, and extension personnel to ensure that access to these technologies is easy, and more important, equitable.

At the Center for International Research, Education, and Development, we prioritize the Virginia Tech mission *Ut Prosim*, or “that I may serve.” The IPM Packages following in this booklet aim to serve farmers growing the healthy, bountiful harvests that feed and nourish communities around the world for decades to come.

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Eggplant, also called aubergine or brinjal, is one of the top ten vegetables grown in the world. The vegetable originated in India and China and Arabic traders introduced it to southern Europe and the Mediterranean. China is the world’s leading eggplant producer with over half of all acreage, and India is second, accounting for roughly one-quarter of total world production. Indonesia, Egypt, Turkey, Iraq, and the Philippines are the other major eggplant-producing countries. Overall, Asia accounts for about 94 percent of the world’s eggplant area, with about 92 percent of world output. African eggplant, *Solanum aethiopicum*, also referred to as scarlet eggplant, bitter tomato, mock tomato, garden egg, or Ethiopian nightshade, is native to Africa. The eggplant is a tropical/semitropical plant belonging to the family Solanaceae and is closely related to the tomato, pepper, and potato. The eggplant is well adapted to grow under high rainfall and high temperatures, as well under dry conditions with irrigation. Eggplant has small/moderate amounts of dietary fiber, vitamins, and micronutrients. It contributes to the diet of people in developing countries when other vegetables are in short supply. Eggplant production in the tropics is challenged by different pests: insects, diseases, nematodes, mites, and weeds, leading to heavy yield losses. This situation continues despite the indiscriminate and intensive use of pesticides to manage these pests.
BACTERIAL DISEASES

Bacterial wilt
[Ralstonia solanacearum (Burkholderiales: Burkholderiaceae)]
This economically devastating disease of eggplant and other crops such as tomato and pepper. Symptoms first appear as flaccidity on young leaves and, when conditions are favorable, quickly develop into complete wilt. Other symptoms include brown discoloration of the vascular system, especially near the soil line, and adventitious roots on the lower stems. Infected plants often die, resulting in a serious crop loss.

FUNGAL DISEASES

Fusarium wilt
[Fusarium oxysporum f. sp. melongenae] (Hypocreales: Nectriaceae)
The fungus survives in the soil for a long time and can spread by farm equipment, irrigation water, and plant debris. The fungus and disease development are favored by a combination of warm soil temperatures and high soil moisture. Symptoms appear as a slight yellowing of foliage and wilting of upper leaves, which later turn dull-green to brown and remain attached to the plant. When the stem and roots are cut diagonally, reddish-brown streaks are visible in the vascular tissues.

Early blight
[Alternaria solani (Pleosporales: Pleosporaceae)]
The fungus survives in soil, infested crop, and weed residues. The pathogen can spread by wind, water, insects, and farm equipment. The disease development is favored by high temperature and prolonged periods of wetness. Major symptoms include dark brown spots with dark concentric rings that develop first on the oldest leaves and progress upward on the plant.

VIRAL DISEASES

Cucumber mosaic virus
(Transmitted by aphids)
Infected leaves show puckering and mosaic coloring can form. Vein necrosis is followed by leaf wilt or deformation. Sometimes fruits are also deformed with yellow streaks.

Tomato yellow leaf curl virus
Kanchanaburi (TYLCV)
(Primarily transmitted by whitefly) Worldwide
Infected plants show leaf yellowing, cupping, and stunting. TYLCV can cause reduction in leaf size, flower and/or fruit drop, and can wipe out fruit production if plants are infected at an early age.

PHYTOPLASMA DISEASES

Little leaf disease
[Phytoplasma/ML0’S]
The disease, which occurs late in the season, is transmitted by grafting as well as by plant hopper, Hishimonus phycitis (Hemiptera: Cicadellidae). The infected plants have small clusters of yellowish leaves, which are soft and narrow. The diseased plants neither produce any flowers nor set fruit. The root system is also stunted.

Fusarium wilt
(Fusarium oxysporum f. sp. melongenae) (Hypocreales: Nectriaceae)
The fungus survives in the soil for a long time and can spread by farm equipment, irrigation water, and plant debris. The fungus and disease development are favored by a combination of warm soil temperatures and high soil moisture. Symptoms appear as a slight yellowing of foliage and wilting of upper leaves, which later turn dull-green to brown and remain attached to the plant. When the stem and roots are cut diagonally, reddish-brown streaks are visible in the vascular tissues.

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Cucumber mosaic virus, Mathew Musumbale Abang
INSECT AND MITE PESTS

**Eggplant fruit and shoot borer**  
*Leucinodes orbonalis* (Lepidoptera: Pyralidae)  
Responsible for extensive yield losses, it is one of the major constraints in eggplant production throughout the tropics in Asia and Africa. The most serious damage is caused by larval feeding inside the fruit, while boring inside the shoot leads to wilting and dying of shoots and gradually slows plant growth. The pest has developed resistance to commonly used pesticides due to farmers’ indiscriminate use for its control. Bt brinjal has been introduced in Bangladesh.

**Spider mites**  
*Tetranychus spp.* (Acarina: Tetranychidae)  
Mites are cosmopolitan and polyphagous pests that feed on various vegetable crops and reduce yields. Mites cause yellow specks on leaves and produce webs on the leaf surface. Mites use web strands to disperse from one plant to another.

**Leafhopper**  
*Amrasca biguttula* (Hemiptera: Cicadellidae)  
Favored by hot and humid weather conditions, this pest causes yellow spots and “hopper burns” on leaves.

**Thrips**  
*Thrips palmi* (Thysanoptera: Thripidae)  
A widely distributed polyphagous pest that infests eggplant, mostly during the dry season. Thrips prefer to feed on foliage but will also feed on fruit. Slightly infested leaves have silvery feeding scars on the lower leaf surfaces while severely infested leaves turn yellow or brown. Infested fruit is scarred and deformed.

**Whitefly**  
*Bemisia tabaci* (Hemiptera: Aleyrodidae)  
The whitefly is a polyphagous pest responsible for crop losses worldwide, however. There are no records of virus transmission in eggplant by this pest.

**Flea beetles**  
*Epitrix fusca* (Coleoptera: Chrysomelidae)  
The flea beetle feeds undersides of leaves, leaving numerous small, round, or irregularly shaped holes, which gives a characteristic “shot hole” appearance to leaves.

**Root knot nematode**  
*Meloidogyne spp.* (Tylenchida: Heteroderidae)  
Nematodes have a wide host range and are most severe in warm areas with long growing seasons. Plants infected by root-knot nematodes are generally less vigorous and healthy. Symptoms of nutrient deficiency and diurnal wilting are visible on leaves due to reduced efficiency of the root system. Presence of bead-like galls on roots is a characteristic of nematode presence.
**Eggplant IPM Techniques**

- Application of fertilizer and compost inoculated with *Trichoderma* spp., neem cake, and vesicular arbuscular mycorrhiza (VaM) fungus improve the nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes and plant diseases.

- Select high-yielding, locally-preferred eggplant varieties that are resistant or moderately resistant to diseases.

- Bt eggplant controls eggplant fruit and shoot borer.

- Treating seeds or seedlings with the *Trichoderma viride* or *T. harzianum* fungi, and *Pseudomonas fluorescens* and *Bacillus subtilis* bacteria to protect seedlings from fungal, bacterial, and nematode attack.

- Use of seedling trays and cocopith reduces contamination. Irrigation should be monitored to prevent excess moisture, which increases the incidence of fungal diseases.

- Proper sanitation i.e., removing plant debris from field, helps in reducing borers, Epilachna beetle, and aphid populations in the field and prevents or delays crop infestation.

- Grafting high-yielding eggplant scions on disease-resistant rootstock of wild solanums, to grow in soil infected with bacterial wilt disease. Grafting increases robustness of plants and yield.

- Neem cake or mustard oil cake alone, or in combination with compost inoculated with *Trichoderma* spp., is effective against soilborne fungal diseases and nematodes. Additionally, they contribute to the build-up of beneficial soil microbes that assist in nutrient absorption by the plants.

- Mulching conserves moisture, harbors natural enemies, and reduces insect pest, mite, and disease incidence. Use reflective mulches or straw mulch to reduce the leaf hopper, whitefly, and thrip populations.

- Setting up yellow sticky sheets in fields helps to reduce populations of aphids, thrips, and whiteflies.

- Inundative release of parasitoids such as *Trichogramma* spp. (Hymenoptera: *Trichogrammatidae*) to control borers while inundative release of lady bird beetles helps to reduce aphid populations. Use of neem-based pesticides for managing leaf hoppers, aphids, whiteflies, and mites. Sprinkler irrigation reduces mite population.

- Sex pheromone traps for the fruit and shoot borer should be set up in the field either at the canopy level or slightly above the canopy level for effectiveness. Once moths are found in the traps, the field should be monitored, and infested shoots, and fruits should be removed and destroyed, where non-BT eggplant is planted.

- Formulations of the fungi *Verticillium*, *Paecilomyces*, *Metarhizium*, and *Beauveria* species and formulations of beneficial nematodes such as *Heterorhabditis* sp. and *Steinernema* sp. may be used for the control of whiteflies, thrips, and *P. absoluta*.

- Application of synthetic chemical pesticides, as needed.

- Application of fertilizer and compost inoculated with *Trichoderma* spp., neem cake, and vesicular arbuscular mycorrhiza (VaM) fungus improve the nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes and plant diseases.
Onion, *Allium cepa*, the second most-produced vegetable in the world, originated in the regions of Afghanistan, Iran, and Pakistan. It is the most widely grown vegetable crop, from the tropics to sub-arctic regions. Onion is consumed both dried and green and the most common are three varieties including yellow, red, and white onions. Several cultivars are grown around the globe including shallots and spring onion. Sulfur derivatives in onions are responsible for the strong smell and taste of onions. Onion crop needs fertile, well-drained soils, and long daylight days to grow well. China, India, and the USA are the largest producers of onion.
**Fungal Diseases**

**Black mold**  
*Aspergillus niger* (Eurotiales: Trichocomaceae)  
Post-harvest black discoloration at neck and clusters of black spores generally on or between scales. This disease causes the entire bulb to dry and shrivel.

**Bulb rot**  
*Fusarium oxysporum* (Hypocreales: Nectriaceae)  
Yellowing, curling, and necrosis at the tip of leaf blades. Pinkish or reddish discoloration appears at the basal plate of onion. When infected plants are pulled up, the bulb often detaches from the roots.

**Damping off**  
*Pythium spp.* (Peronosporales: Pythiaceae)  
Infection usually occurs in seedlings and symptoms appear as water-soaked lesions on lower stems and a watery rot that occurs on the roots. Infected tissue becomes soft and constricted at the base, causing the plant to topple. Favorized by ill-drained conditions or excessive moisture in field.

**Purple blotch**  
*Alternaria porri* (Peronosporales: Pleosporaceae)  
A destructive foliar disease favored by cooler climate. Symptoms appear as chlorotic lesions on leaves with concentric black, velvety rings of fungal sporulation. These lesions then girdle leaves causing drying and falling off.

**White rot**  
*Sclerotium cepivorum* (Helotiales: Sclerotiniaceae)  
Can be very damaging to onions. White rot causes pre-mature yellowing, wilting, and dropping of leaves, followed by destruction of the root system and rotting of bulbs. Affected bulbs and roots are covered with a thick, white mycelial growth with numerous black or brown colored sclerotia.

**Rust**  
*Puccinia porri* (Pucciniaceae)  
Small white flecks appear on leaves and stem which develop into orange colored circular oval shaped pustules. Heavily infected leaves turn yellow and die premature. Bulb size and quality are also affected.

**Smut**  
*Urocystis colchici* and *U. cepulae* (Urocystidiales: Urocystidiaceae)  
Symptoms appear as dark brown or black thickened lesions on cotyledons and young leaves. Large lesions may cause leaves to curve downward. Raised blister-like lesions may also occur near the base of scales of older plants. Infection progresses inward from leaf to leaf at the base of the plant. Infected plants become stunted and may die within 3-5 weeks after emergence.

**Viral Diseases**

**Iris yellow spot virus**  
It is a tospovirus that is transmitted by onion thrips, *Thrips tabaci*. It causes straw-colored, dry spindle, or diamond shaped lesions on leaves and scapes. These lesions may have distinctive green centers. Dry, elongated lesions or flecks may resemble thrips injury. Infected seed stalks and leaves may lodge later in the growing season. Plant vigor and bulb size are reduced.

**Onion yellow dwarf virus**  
It is transmitted from plant to plant by the green peach aphid, *Myzus persicae*, and other aphids in a non-persistent manner. Infected leaves show symptoms ranging from yellow streaks to complete yellowing. Leaves are sometimes wrinkled and flattened and tend to bend over. Bulbs are usually solid but undersized.
Onion thrips
*Thrips tabaci* (Thysanoptera: Thripidae)
A polyphagous pest feeding on more than 300 plant species. Thrips feed on leaves by rasping and sucking cell contents causing silvery sheen or streaks on leaves. Several topsoviruses, such as *Iris yellow spot virus*, are transmitted by onion thrips and are responsible for serious economic losses.

Beet armyworm
*Spodoptera exigua* (Lepidoptera: Noctuidae)
A major pest on vegetable crops with a wide host range. Young larvae feed inside the leaves, leaving only the outer cuticle and causing a characteristic “window-paning” on leaves.

Army worm
*Spodoptera litura* (Lepidoptera: Noctuidae)
A polyphagous pest that feeds on wide host range of crops in the families Solanaceae, Malvaceae, Cruciferae, Fabaceae, and others. Early larval instars feed in clusters, skeletonizing the leaves.

Black onion aphid
*Neotoxoptera formosana* (Hemiptera: Aphididae)
Forms dense colonies on leaves and reduces value of crop due to feeding (sap sucking) and physical presence of aphids on leaf onions.

Onion fly
*Delia antiqua* (Diptera: Anthomyiidae)
Serious pest of onion and other related allium crops. Larval feeding on the roots/base of the plant leads to distorted growth of bulbs and rotting of tissues. Young seedling may wilt and die due to larval feeding. Often the bacterium *Bacillus carotovorus* enters the maggot damaged areas and causes soft rot.

Leafminers
*Liriomyza* spp. (Diptera: Agromyzidae)
Tunneling of leaves by larvae results in thin white trails/mines on leaves, causing reduced photosynthesis and yield.
Soil application of fertilizers and compost inoculated with *Trichoderma* spp., neem cake, and vesicular arbuscular mycorrhiza (VAM) fungus improves the nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes, plant diseases, and weeds.

- Selection of healthy bulbs.

- Treating bulbs with the *Trichoderma viride*, *T. harzianum*, *Pseudomonas fluorescens*, and *Bacillus subtilis* protects sprouts from fungal diseases especially bulb rot.

- Crop rotation with non-host crops help in reducing incidence of soil-borne diseases.

- Mulching conserves moisture, harbors natural enemies, and reduces insect pest, mite, and disease incidence. Mulching, especially straw mulch has been helpful in reducing thrips population and improving crop growth.

- Setting up sticky traps of different colors, in the field have been helpful in reducing populations of thrips and leafminers.

- Use pheromone traps for monitoring and management of armyworms, *Spodoptera* spp.

- In addition to the use of nuclear polyhedrosis viruses (NPVs) against *S. litura*, formulations of the fungi *Verticillium*, *Paecilomyces*, *Metarhizium*, and *Beauveria* species and formulations of beneficial nematodes such as *Heterorhabditis* sp. and *Steinernema* sp. can be used.

- Neem oil, neem seed kernel extract, and commercial formulations of azadirachtin are effective in controlling the insect pest populations.

- Application of safe and approved synthetic pesticides as needed.
Cruciferous vegetables (Brassicaceae) are economically the most important vegetable crops throughout the world. Most commonly consumed crucifer vegetables are, cauliflower, cabbage, kale, bok choy, radish, mustard plant, broccoli, and brussels sprouts. They are normally considered temperate crops but are also important in the tropics. In the tropics, this crop does well on higher elevations. These crops are also grown in home gardens worldwide. Cruciferous vegetables have high nutritional requirements. They require intensive top dressing with mineral fertilizers and frequent irrigation. The soil should be constantly kept slightly moist. They are valuable sources of nutrition, including Vitamin A, C, Niacin, Folic acid, and dietary fiber. In recent years, crucifer production has been seriously affected by a steady increase in pests and diseases that reduce the yield and quality of produce. This increase could be due to the indiscriminate use of pesticides and the development of pesticide resistance.
Black Rot  
[Xanthomonas campestris pv. campestris (Xanthomonadaceae)]  
Considered the most important disease of crucifer crops worldwide. All crucifer crops are susceptible to black rot. Plants can be infected during any growth stage. Initial symptoms are seen as 1–3 cm irregular yellow areas along the leaf margins. These lesions expand toward the midrib giving the affected areas a wedge or V-shape. These lesions coalesce as the disease progresses, giving leaf margins a scorched appearance and severely affected leaves may drop off. V-shaped marginal lesions occur when bacteria enter the leaves through hydathodes (natural openings at the vein ends on leaf margins). Bacteria can also enter leaves through wounds due to insect damage or root injury. Soft rot follows the invasion of petioles and head leaves of brassicas.

Bacterial soft rot  
[Pectobacterium carotovorum=Erwinia carotovora subsp. atroseptica (Enterobacteriales: Pseudomonadaceae)] and [Pseudomonas marginalis (Pseudomonadaceae)]  
It is another significant disease of crucifers. It occurs on all crucifer crops but it is more prevalent on Chinese cabbage and head cabbage. The disease can occur in the field, or in transit or storage. Early symptoms appear as water-soaked lesions, which expand rapidly, and the affected areas turn soft, mushy, and rotten. Bacterial soft rot-infected plants give off an unpleasant sour odor.

Xanthomonas leaf spot  
[Xanthomonas campestris pv. campestris]  
Occurs on all cultivated crucifers. Symptoms appear as depressed, translucent water-soaked spots on leaves, but lesions can also occur on cotyledons, flowers and fruits. The leaf spots develop into brown-to-black-colored circular lesions surrounded by chlorotic margins. Dry tissue falling from the center of lesions give a shot hole appearance to the leaves. Symptoms are generally confined to tissues between veins but necrotic streaks may be present along the sides of the veins. Under severe infestations, the entire leaf may collapse.

Downy mildew  
[Hyaloperonospora parasitica (Peronosporales: Peronosporaceae)]  
Widespread throughout the world. The extent and severity of the infection are more pronounced in younger plants than older plants. All aerial plant parts can become infected; however, symptoms appear primarily on leaves and inflorescences. Symptoms appear as dark-colored specks on leaves, usually first on the underside of the leaf. A distinctive characteristic is the presence of a fluffy whitish-grey mass of conidiophores and conidia on the underside of leaves. A yellow irregular-shaped area appears on the upper side of the leaf corresponding to the sporulation growth on the underside. On the cabbage heads or cauliflower curds, symptoms appear as dark, sunken spots, and dark brown internal streaks can develop on heads.

Alternaria leaf spot  
[Alternaria brassicae, Alternaria brassicicola (Pleosporales: Pleosporaceae)]  
Most crucifers are susceptible to alternaria leaf spot and plants are susceptible at all growth stages. Infection of seedlings may cause damping off or stunted plants. The most common symptom of Alternaria diseases is small, yellow, dark brown-to-black circular leaf spots with concentric rings. These spots enlarge and coalesce into bigger necrotic areas. Lower leaves are more susceptible than upper young leaves. Lesions can occur on petioles, stems, flowers, pedicels, and seedpods.

Fusarium yellows  
[Fusarium oxysporum f. sp conglutinans]  
Head cabbage is the most susceptible host crop, but Fusarium Yellows can also affect other brassica crops. It could affect any growth stage, from seedlings to mature plants. Initial symptoms appear as a dull yellowish green discoloration of leaves and plant stunting. Discoloration of leaves is more intense on one side of the plant and results in twisting of leaves and stems. The disease is more pronounced on lower leaves and progresses upwards. Lower leaves turn brown and brittle and drop off prematurely. Under severe infestations, young seedlings and plants are quickly killed. Vascular system develops a distinctive brown discoloration.

Powdery mildew  
[Erysiphe cruciferarum (Erysiphales: Erysiphaceae)]  
Symptoms occur as white lesions on the upper surface of foliage and later appear as a powdery sugar-like growth. It could also occur on shoots and sometimes on flowers. Leaves turn yellow, die, and fall off. The disease reduces crop yield and quality.

Clubroot  
[Plasmodiophora brassicae (Plasmodiophorales: Plasmodiophoraceae)]  
Most crucifer crops are susceptible to clubroot. It develops extensively on roots before any above-ground symptoms are observed. Swelling of fine roots, secondary roots, and taproots results in the formation of large spindle-shaped club roots. It impairs the ability of plants to efficiently absorb water and nutrients and the plants become stunted and wilted. The roots also become more susceptible to invasion by soft rot pathogens.
**Damping off and Wirestem**  
*Pythium* spp. (Peronosporales: Pythiales) and *Rhizoctonia solani* (Cantharellales: Ceratobasidiaceae)  
All plant growth stages are susceptible. When young seedlings are attacked, before or after emergence, it is referred to as damping off. When older seedlings are attacked, the cortical tissue is damaged. The lower stem becomes constricted and becomes dark-brown near the soil surface. This symptom is called wire-stem. Such plants may die when stressed or produce a stunted, unmarketable crop. When lower leaves near the soil line develop large water-soaked lesions, it is called bottom rot. If the infection from lower leaves progresses into cabbage heads, causing decay, it is called head rot.

**White mold**  
*Sclerotinia sclerotiorum* (Helotiales: Sclerotiniaceae)  
The pathogen has a wide host range and affects all crucifers and other vegetables. The appearance of symptoms varies with host plant and weather conditions. Symptoms appear as water-soaked lesions on the stem, leaves, or head. These lesions enlarge and are covered by cottony white mycelial growth. Mycelial growth may spread to other plant tissues. Infected plants may wilt, topple or even die. Later on, small black-colored hard sclerotia develop on the mycelial growth. The disease can occur in the field or during transportation.

**Ring spot**  
*Mycosphaerella brassicicola* (Capnodiales: Mycosphaerellaceae)  
Symptoms appear as water-soaked lesions on leaves and stems and expand to form concentric yellow rings, giving a tattered appearance to leaves and stems.

**Cyst nematode**  
*Heteroderus cruciferae* (Tylenchida: Heteroderidae)  
In the beginning, plants appear to have a nutrient deficiency followed by wilting, especially in hot weather. The nematode produces lemon-shaped, tan, white-hard cysts on the root surface. Infected plants eventually die.

**Root-knot nematode**  
*Meloidogyne* spp. (Tylenchida: Heteroderidae)  
The root-knot nematodes have a wide host range and are most severe in warm areas with long growing seasons. Plants infected by root-knot nematodes are generally less vigorous and healthy. Symptoms of nutrient deficiency and diurnal wilting are visible on leaves due to the reduced efficiency of the root system. The presence of bead-like galls on roots is characteristic of nematode presence.

**Turnip mosaic virus**  
Also known as rutabaga virus, it is the most prevalent and widespread virus infecting crucifers, especially brassicas, and is transmitted by aphids. Symptoms appear as a distinct mosaic pattern on leaves, necrotic flecks, and streak or ringspots, depending on the host and virus strain. Following infection, systemic mosaic symptoms develop rapidly on young plants. Infected plants may be stunted, produce reduced yields, and are vulnerable to secondary infections.

**Cauliflower mosaic virus**  
It is transmitted by aphids; *Brevicoryne brassicae, Myzus persicae, Hyadaphis erysimi*. Symptoms include chlorosis along leaf veins, dark green bands, necrosis, and stunting of plants.

**Radish mosaic virus**  
Symptoms include mosaic, ring spot, leaf distortion, vein necrosis, and leaf enations. In cauliflower and cabbage, chlorotic and necrotic lesions are also seen. It is transmitted by the chrysomelid beetles e.g. crucifer flea beetles, spotted cucumber beetles, and tobacco flea beetles.

**Turnip yellows virus**  
Aphids transmit TuYV disease and symptoms appear as chlorotic spots followed by yellowing and thickening of leaves.

**White mold**  
*Sclerotinia sclerotiorum* (Helotiales: Sclerotiniaceae)  
The pathogen has a wide host range and affects all crucifers and other vegetables. The appearance of symptoms varies with host plant and weather conditions. Symptoms appear as water-soaked lesions on the stem, leaves, or head. These lesions enlarge and are covered by cottony white mycelial growth. Mycelial growth may spread to other plant tissues. Infected plants may wilt, topple or even die. Later on, small black-colored hard sclerotia develop on the mycelial growth. The disease can occur in the field or during transportation.

**White spot**  
*Pseudocercosporella capsellae*; sexual stage: *Mycosphaerella capsellae* (Capnodiales: Mycosphaerellaceae)  
It can occur on leaves, stems, and pods. White-to-tan-colored, round or irregular spots develop on leaves, which later become ash-gray-to-white with a brownish margin. As the leaves age, the center of the lesions may fall out giving a shot-hole appearance. Under severe infestations, defoliation may occur.
Aphids
[Brevicoryne brassicae, Myzus persicae, Hydaphis erysimi (Hemiptera: Aphididae)]
Aphids suck the sap from plants, which results in yellowing, curling, and deformation of leaves. Continuous feeding by aphids leads to yellowing, wilting, and stunting of plants. Honeydew secretion leads to the development of sooty mold. Aphids also vector several important viruses on crucifers including Cauliflower mosaic virus, Turnip yellow virus, Turnip mosaic virus, etc.

Whitefly
[[Bemisia tabaci] Hemiptera: Aleyrodidae]
Whiteflies cause damage by sucking and secreting sticky honeydew. Black sooty mold grows over the honeydew. Extensive feeding may result in stunting, poor growth, defoliation, and reduced yields.

Cutworm
[Agrotis spp., (Lepidoptera: Noctuidae)]
Seedlings of young plants are cut very near or below the soil line. It is common to see several plants in a row cut off or wilting due to cutworm damage. Damage is more severe in fields where cutworms are present before planting. Larvae causing the damage are usually active at night and hide during the day in the soil at the base of the plants or in plant debris of toppled plant.

Tomato fruit worm (corn earworm)
[Helicoverpa armigera (Lepidoptera: Noctuidae)]
Young larvae prefer to feed on leaves but larger larvae bore into heads. Feeding holes filled with excreta are characteristic of larval damage. Severe damage leads to yield losses.

Cabbage head caterpillar
[Crocidoloma pavonana (Lepidoptera: Crambidae)]
The larvae generally feed on the leaf surface but as they grow older, they also feed inside cabbage heads.

The larvae feeding on the leaf surface leave major veins intact, but young leaves may be completely eaten. Eggs of the cabbage head caterpillar are parasitized by Trichogramma spp. (Hymenoptera: Trichogrammatidae), and the larvae are parasitized by Aphanogmus spp.

Cabbage looper
[Trichoplusia ni (Lepidoptera: Noctuidae)]
The larvae feed by chewing holes in leaves and also bore into the head. The larval feeding and frass left behind to make the produce unmarketable. Larval feeding on seedlings causes stunting and death of seedlings. The parasitoids, Voria ruralis, Eucelatoria armigera (Diptera: Tachinidae), Microplitis brassicae, and Chelonus texanus (Hymenoptera: Braconidae) are reported on the cabbage looper. Bacillus thuringiensis is effective in killing larvae.

Cabbage webworm
[Hellula undalis (Lepidoptera: Crambidae)]
The young larvae mine the leaves and feed on the underside of the leaves, chewing small holes. Webbing on the surface of inner leaves is seen and these webs are covered with insect remains and frass. Larger larvae can burrow into stems, and leaves. Larval feeding on growing point of seedlings causes severe damage.

Diamondback moth
[Plutella xylostella (Lepidoptera: Plutellidae)]
Plants at all growth stages are susceptible to damage. Larvae feed by chewing holes in leaves and damage is confined to areas between veins. Young larvae feed on undersides of the leaves leaving the epidermis intact and giving a windowpane appearance. On young plants, the growing tips are eaten and plants are stunted. The larvae also attack developing cabbage heads, making them prone to attack by pathogens. Egg parasitoid Trichogrammatoides bactrae (Hymenoptera: Trichogrammatidae), larval parasitoids Diadegma spp. (Hymenoptera: Ichneumonidae), and Cotesia sp. (Hymenoptera: Braconidae), and pupal parasitoid Diadromus collaris (Hymenoptera: Ichneumonidae) are effective against diamondback moth.

Cabbage butterflies
[Pieris brassicae and P. rapae (Lepidoptera: Pieridae)]
Young larvae cause damage by scraping the leaves and later by chewing irregular holes in leaves. The larvae cause skeletonization of leaves.

Cabbage shield bug
[Eurydema pulchrum (Hemiptera: Pentatomidae)]
Feeding by nymphs and adults causes necrotic spots on leaves. Damage is confined to older, outer leaves and is localized.

Painted bug
[Bagrada cruciferarum (Hemiptera: Pentatomidae)]
Nymphs and adults feed by sucking sap from tender plant parts, causing yellowing and drying of leaves and premature leaf fall. Heavy infestations reduce growth and yield.

Striped flea beetle
[Phyllotreta striolata (Coleoptera: Chrysomelidae)]
Young leaves have small, round holes, which can coalesce to form large holes as leaves mature giving a “shot-hole appearance.” Under severe infestation, seedlings may be killed.
• Application of fertilizers and compost inoculated with Trichoderma spp., neem cake, and Vesicular Arbuscular Mycorrhiza (VaM) to improve nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes and fungal plant diseases.

• Crop rotation with non-host crops helps in reducing the incidence of soil-borne diseases.

• Select high-yielding, locally preferred crucifer variety that is resistant or moderately resistant to diseases such as Turnip mosaic virus, clubroot, Fusarium yellows and others.

• Grow transplants in mesh-covered seedbeds to prevent aphids, whiteflies, diamondback moth, and flea beetles. Discard diseased seedlings.

• Treating seeds with the Trichoderma viride or T. harzianum fungi, and Pseudomonas fluorescens and Bacillus subtilis bacteria protects seedlings from fungal and bacterial diseases, and induces plant defense against pests.

• Hot water seed treatment is effective against bacterial pathogens like Xanthomonas.

• Use of seedling trays and coconut pith medium reduces contamination. Irrigation should be monitored to prevent excess moisture, which increases the incidence of diseases like black rot, Xanthomonas leaf spot, etc.

• Use of neem-based formulations for managing aphids, whiteflies, and other pests.

• Inundative release of Trichogramma spp., Telenomus spp., and Bracon spp. for control of lepidopteran pests.

• Bacillus thuringiensis is effective against diamondback moth and other lepidopteran pests.

• Use safe synthetic pesticides, if needed.
The pepper (*Capsicum* sp.), originated in Mesoamerica and is now widely cultivated throughout the tropics and subtropics. Pepper contains significant amounts of vitamins A, C, and B, calcium, and iron. Peppers belong to the Solanaceae family, which includes eggplant, potato, tobacco, and tomato. Peppers grow well in warm climates and have a relatively long growing season. China, Mexico, Turkey, Indonesia, India, Spain, and the USA are the world’s leading producers of pepper. In recent years, there has been an increase in pepper production worldwide, possibly due to the high nutritional value of pepper. Pepper production in the tropics is challenged by insects, diseases, nematodes, mites, and weeds, leading to heavy yield losses.
Bacterial Diseases

**Bacterial Leaf spot**
[Xanthomonas campestris pv. vesicatoria (Xanthomonadaceae)]
Water-soaked lesions are observed on the leaves, fruits, and stem. These lesions gradually become necrotic and brown in the center. These necrotic spots can coalesce and cause chlorosis.

**Bacterial wilt**
[Ralstonia solanacearum (Burkholderiales: Burkholderiaceae)]
This economically devastating disease of tomato is often lethal to pepper and other solanaceous crops like eggplant, potato, and tobacco. Symptoms first appear as flaccidity on young leaves and, when conditions are favorable, quickly develop into complete wilt. Other symptoms include brown discoloration of the vascular system, especially near the soil line, and adventitious roots on the lower stems. Infected plants often die, resulting in a severe reduction to yield.

**Fungal Diseases**

**Potato virus Y**
It is common worldwide, especially under warm climatic conditions. Symptoms appear as vein clearing that progresses into a mosaic, dark green vein banding of leaves. Stem necrosis and defoliation also occurs in some cases. Infection at an early stage of plant development could lead to a 100% yield loss. It is transmitted by aphids.

**Gray mold**
[Botrytis cinerea (Helotiales: Sclerotiniaceae)]
The fungus can affect young seedlings, flower petals, injured fruit, or senescing leaves. Initially, the symptoms appear as a dark, water-soaked, slimy lesion. The affected areas turn brownish-gray and powdery-looking as sporulation develops. Young seedlings may show damping-off near the soil line.

**Powdery mildew**
[Leveillula taurica (Imperfect stage = Oidiopsis taurica) (Erysiphales: Erysiphaceae)]
This fungus usually occurs on older leaves just before fruit sets. A patchy white growth occurs on leaves, which later on covers the entire lower leaf surface. The upper surface of leaves may show yellowish or brownish patches. Infected leaves roll upward and later drop off.

**Damping-off and rot**
[Pythium spp. (Peronosporales: Pythiaceae); Rhizoctonia solani (Cantharellales: Ceratobasidiales); Fusarium spp. (Hypocreales: Nectriaceae)]
It can occur before or after plant emergence and can damage seedlings after transplanting. Often seedlings fail to emerge from seeds. In post-emergence, seedlings are stunted, wilted, and topple over.

**Cercospora leaf spot**
[Cercospora capsici (Capnodiales: Mycosphaerellaceae)]
Small, round to oblong lesions with grey centers occur on leaves, stalks, and leaf stems. Infected leaves often drop off.

**Anthracnose**
[Colletotrichum acutatum and C. gloeosporiodes] (Glomerellales: Glomerellaceae)]
Primarily the fruits are affected. Lesions are round and sunken. The center of the lesion is covered by pink-colored sporulation.

**Phytophthora rot**
[Phytophthora capsici (Peronosporales: Peronosporaceae)]
This is a very common fungal disease, which causes dead and wilted plants, especially in poorly drained soils. The crown region near the base is usually dark, sunken, and necrotic. Sometimes, vascular discoloration is observed.

**Chaoanephora blight**
[Choanephora cucurbitarum (Mucorales: Choanephoraceae)]
Pepper plants are susceptible from seedling to the early flowering stage, but extensive damage occurs in the rainy season. Infected tissue turns brown or black and infected young fruits drop off. Other symptoms include wilting of leaves and stems that appear wet and green, with bark that peels off and shreds easily.

**Verticillium wilt**
[Verticillium albo-atrum, V. dahlia (Glomerellales: Plectosphaerellaceae)]
In the beginning, the leaves roll inwards with some foliar wilting. As the disease progresses, yellowing of leaves, premature leaf fall, wilting, and stunting of plants occur. The dark brown discoloration is seen in the vascular tissue that extends from the soil line to the lower branches of the plant.
INSECT AND MITE PESTS

Broad mite
[Polyphagotarsonemus latus (Acarina: Tarsonomiidae)]
A serious pest of pepper, eggplant, tomato, beans and others. It affects tender leaves in the growing shoots. The affected shoots become elongated, and the leaves become curled and distorted. Fruits are malformed and scarified.

Silver leaf whitefly
[Bemisia tabaci (Hemiptera: Aleyrodidae)]
Responsible for heavy crop losses worldwide, whiteflies damage peppers by sucking and secreting sticky honeydew, which grows black sooty mold. Extensive feeding may result in stunting, poor growth, defoliation, and reduced yields. It also transmits begomovirus diseases.

Spiraling whitefly
[Aleurodicus dispersus (Hemiptera: Aleyrodidae)]
Feeding by large populations can cause the desiccation of plants. Honeydew secreted by whiteflies also promotes the growth of sooty mold and thus affects the normal growth of plants. It does not transmit virus diseases.

Aphids
[Aphis gossypii (Hemiptera: Aphididae)]
A cosmopolitan and polyphagous pest that feeds on various crops hosts like cucurbits, peppers, eggplant, okra, cotton, and others. Aphids suck the sap from plants, which results in yellowing, curling, and deformation of leaves. Honeydew secretion leads to the development of sooty mold. Aphids also act as vectors for several important viruses on pepper including the Cucumber mosaic virus, Potato virus Y, and Pepper veinal mottle virus.

Chili thrips
[Scirtothrips dorsalis (Thysanoptera: Thripidae)]
Thrips feeding leads to curling and dropping of leaves, and buds drop if fed upon. Feeding also scars the fruit.

Pepper gallfly
[Asphondylia capsici (Diptera: Cecidomyiidae)]
Larvae feed inside the fruits and young fruits become small and deformed. When older fruits are attacked, the fruits become twisted and deformed.

Tomato fruit worm (Corn earworm)
[Helicoverpa armigera (Lepidoptera: Noctuidae)]
This major pest of food and fiber crops has a wide host range, including pepper, tomato, corn, eggplant, crucifers, melons, beans, and others. Most of the damage is caused by fruitworm larvae feeding on flowers, and fruits.
• Application of fertilizers and compost inoculated with *Trichoderma* spp., neem cake, and vesicular arbuscular mycorrhiza (VaM) fungus, improve the nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes and other plant diseases.

• Select a high-yielding, locally preferred pepper variety that is resistant or moderately resistant to diseases such as bacterial wilt and Phytophthora blight.

• Grow seedlings in covered seedbeds to prevent aphids, whiteflies, and transmission of viral diseases. Discard infected seedlings.

• Treating seeds/seedlings with the *Trichoderma viride* or *T. harzianum* fungi, *Pseudomonas fluorescens*, and *Bacillus subtilis* bacteria provides protection of crop from fungal, bacterial, and nematode attacks, increases seedling vigor, and induces plant defense against pests.

• Use of seedling trays with cocopith reduces contamination. Irrigation should be monitored to prevent excess moisture, which increases the incidence of fungal diseases.

• Before sowing, remove and destroy plant debris or infested plant material from the field to avoid fungal diseases. Remove weeds, which may serve as a reservoir for disease.

• Mulching conserves moisture, harbors natural enemies, and reduces insect pest, mite, and disease incidence. Use reflective mulches or straw mulch to reduce the aphid, whitefly, and thrip populations.

• Setting up yellow sticky sheets in fields reduce populations of pests such as aphids, thrips, and whiteflies.

• Use of formulations of the fungi *Verticillium*, *Paecilomyces*, *Metarhizium*, and *Beauveria* species, bacterium *Bacillus thuringiensis*, botanical neem, and beneficial nematodes such as *Heterorhabditis* sp. and *Steinernema* sp.

• Use safe synthetic chemical insecticides, if needed.

Farmers add coconut husk to seedling trays
The tomato, Mesoamerican in origin, has been distributed throughout the world since the 1950s. In 2010, over 145 million metric tons of tomato were produced globally. Tomatoes are widely grown in subsistence agriculture — mostly in outdoor environments in the tropics and in greenhouses in temperate regions — and used as a key part of local diets. Because the tomato (Solanum lycopersicum) is an affordable source of vitamins, micronutrients, and fiber for people throughout the tropical world, it is an extremely valuable crop. Pest management is a challenge in subsistence agriculture. Due to damage from insects, mites, bacteria, fungi, viruses, nematodes, and weeds, yield loss in tomatoes is high: 40%. This situation prevails in spite of intensive and widespread pesticide use — to the point of chronic misuse — to manage these pests.
**Viruses and Diseases**

**Viral Diseases**

*Peanut bud necrosis virus (PBNV)*

PBNV has a wide host range and is transmitted by thrips. It may cause serious economic damage to vegetables, legumes, and ornamental crops. This virus causes tomato yield reduction in both quantity and marketability, reduces the nutritional quality of fruits, and shelf life.

*Tomato yellow leaf curl virus (TYLCV)*

One of the most devastating tomato virus diseases, TYLCV is transmitted by the whitefly *Bemisia tabaci*. Infected tomato plants show leaf yellowing, cupping, and stunting. TYLCV can cause reduction in leaf size, flower and fruit drop, and wipe out fruit production if plants are infected at an early age.

**Fungal Diseases**

*Late blight* [*Phytophthora infestans* (Peronosporales: Peronosporaceae)]

This pathogen survives on volunteer plants or abandoned tomatoes between growing seasons. The fungus and disease are favored by the combination of cool nights, warm days, and moist weather. Major symptoms include small, water-soaked lesions on leaves that develop into larger lesions and rings; leaves will eventually shrivel and die. Fruit lesions can invade the whole fruit. Decaying fruit and vines may also develop secondary infections such as rot.

**Bacterial Diseases**

*Bacterial wilt* [*Ralstonia solanacearum* (Burkholderiales: Burkholderiaceae)]

This economically devastating disease of tomatoes and other crops like eggplant. Symptoms first appear as flaccidity on young leaves and, when conditions are favorable, quickly develop into complete wilt. Other symptoms include brown discoloration of the vascular system, especially near the soil line, and adventitious roots on the lower stems. Infected plants often die, resulting in a severe reduction to yield.
**Tomato fruitworm** (corn earworm) *Helicoverpa armigera* (Lepidoptera: Noctuidae)
This major pest of food and fiber crops has a wide host range, including tomato, corn, eggplants, crucifers, melons, beans, and others. Most of the damage is caused by fruitworm larvae feeding on flowers, and fruits.

**Army worm** *Spodoptera litura* (Lepidoptera: Noctuidae) A polyphagous pest that feeds on wide host range of crops of the families Solanaceae, Malvaceae, Cruciferae, Fabaceae, and others. Early larval instars and caterpillars feed in clusters skeletonizing the leaves. Later instars feed on leaves and fruits.

**Whitefly** *Bemisia tabaci* (Hemiptera: Aleyrodidae) Responsible for heavy crop losses worldwide, often related to its role in transmitting viral diseases including TYLCV.

**Thrips** *Frankliniella occidentalis* (Thysanoptera: Thripidae)
Thrips are polyphagous, feeding on a wide host range. Several tospoviruses, such as *Peanut bud necrosis virus* (PBNV) and *Tomato spotted wilt virus* (TSWV), are transmitted by thrips and are responsible for major economic damages to tomato.

**South American tomato leafminer** *Phthorimaea* (*Tuta*) *absoluta* (Lepidoptera: Gelechiidae) The tomato leafminer causes damage primarily to tomato but could also affect other solanaceous crops. Larval mining of tomato leaves may result in a 100% loss of the crop.
• Soil application of fertilizers and compost inoculated with *Trichoderma* spp., neem cake, and vesicular-arbuscular mycorrhiza (VAM) fungus improves the nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes, plant diseases, and weeds.

• All seedlings in the nursery should be examined for symptoms of viral diseases, and suspected seedlings should be removed from the planting material. *Peanut bud necrosis virus* transmitted by thrips is a serious problem on tomatoes in India. Roguing infected seedlings before transplanting will decrease the incidence of the disease.

• Monitoring crops and removing and disposing of *Peanut bud necrosis virus*-infected plants within the first 45 days after transplanting should be carried out to prevent disease spread by thrips within the field.

• By grafting high-yielding tomato scions on disease-resistant rootstock of wild *solanums*, healthy tomatoes grow in soil known to be infected with bacterial wilt disease. Grafting increases the yield and robustness of plants.

• Keeping an area free of tomato and pepper crops for two months before planting a tomato crop reduces the incidence of the TYLCV transmitted by the whitefly *B. tabaci*.

• Staking tomatoes in the field increases proper aeration and exposure to sunlight and prevents shoots and fruits from touching the soil. This also reduces late blight infection and fruit rot.

• Mulching conserves moisture, harbors natural enemies, and reduces insect pest and disease incidence.

• Setting up yellow sticky sheets in fields reduces populations of aphids, thrips, and whiteflies.

• Pheromone traps for the tomato fruit worm *H. armigera* the army worm *S. litura* and *P. absoluta* should be set up in the field. Once pests are found in the traps, the field should be monitored, and a specific biopesticide should be used if necessary.

• In addition to the use of nuclear polyhedrosis viruses (NPVs) against specific insect pests, formulations of the fungi *Verticillium*, *Paecilomyces*, *Metarhizium*, and *Beauveria* species and formulations of beneficial nematodes such as *Heterorhabditis* sp. and *Steinernema* sp. may be used for the control of whiteflies, thrips, and leafminers.

• Inundative release of parasitoids such as *Trichogramma* spp., *T. remus*, and *Bracon* spp. controls caterpillar pests such as *H. armigera*, *S. litura*, and *P. absoluta*. 

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**Tomato staking**
Cucumber (Cucumis sativus: Cucurbitaceae), is an annual plant and is grown for its edible fruit. It originated from the foothills of the Himalayas and at present various varieties are grown around the globe. China, India, Russia, and the USA are the major producers. This crop requires warm, dry conditions, fertile, well-draining soil, rich in organic matter. Some varieties require pollinators, whereas others do not and both seeded and seedless varieties are available. Cucumbers also require a continuous supply of water. Major insect pests are melon fruit fly, aphids, whiteflies, cucumber beetles, and flea beetles. Major diseases are leaf blight, leaf spot, downy mildew, anthracnose, and virus diseases.
Fungal Diseases

Alternaria leaf blight
[Alternaria cucumerina, Alternaria tenuis, Alternaria alternata (Pleosporales: Pleosporaceae)]
Major symptoms of this disease include, small, yellow-brown spots with a yellow or green halo which first appear on the oldest leaves, lesions expand with concentric pattern and coalesce at later stages and causing leaf dying. High temperature and frequent rainfall is favorable for this disease. Watering the plants from the base to reduce periods of leaf wetness to avoid the development of disease, crop rotation, removal of crop debris, and use of fungicide could help manage this disease.

Anthracnose
[Colletotrichum orbiculare (Glomerellales: Glomerellaceae)]
This disease causes brown roughly circular lesions with yellow edges on all plant parts including leaves, petioles, stems, and fruits. Warm weather is favorable for this disease. The use of certified seeds, resistant varieties, and crop rotation could help in managing the disease.

Belly rot (Fruit rot, Damping-off)
[Rhizoctonia solani (Cantharellales: Cera- tobasidiales)]
Belly rot causes discoloration on fruit with mold growing on rotting areas and eventually seedling collapses. Warm and humid conditions are favorable for this disease. Deep tilling, use of plastic mulch, proper drainage, and fungicides could help in managing the disease.

Cucurbit leaf spot
[Cercospora citrullina (Capnodiales: Myco- sphaerellaceae)]
Small spots with brown centers appear on the older leaves, at later stages the centers of the lesions become brittle and crack. This fungus spreads with wind and water and can survive on plant debris. It is prominent in tropical and subtropical regions. Removal of diseased plants and debris and deep plowing could prevent further spread.

Downy mildew
[Pseudoperonospora cubensis (Peronosporales: Peronosporaceae)]
Downy mildew creates fluffy purplish mildew on the underside of leaves and yellow spots on the upper side of leaves. Cool and humid conditions increase the presence of this disease. Avoiding overcrowding plant and, overhead irrigation and fungicide application could manage the disease.

Fusarium wilt/Cucumber wilt/Foot-rot
[Fusarium oxysporum, Fusarium equisetii, Fusarium solani (Hypocreales: Nectria- ceae)]
Major symptoms include rotting of seedling stems at the soil line, brown lesions on one side of the stem, and discoloration of tissue inside vines. Warm and moist soil encourages this disease. Crop rotation could help manage the disease.

Gummy stem blight/vine decline
[Didyymella bryoniae (Pleosporales: Didy- mellaceae)]
Major symptoms include lesions between veins of leaves and stems. Infected seeds could spread the disease. The use of disease-free seeds, seed treatment with Trichoderma and fungicides and crop rotation helps in managing this disease.

Powdery mildew
[Erysiphe cichoracearum, Sphaerotheca fuliginea (Erysiphales: Erysiphaceae)]
Powdery mildew first appears as white powdery spots on the upper surfaces of leaves, stems, and fruits, and at later stages, whole leaves and stems get covered with white powdery mildew. Infected leaves become yellow, distorted, and drop prematurely. Shady conditions increase the disease and wind is a major way to spread the disease. Resistant varieties are available.

Septoria leaf spot
[Septoria cucurbitacearum (Capnodiales: Mycosphaerellaceae)]
This disease initially causes small dark water-soaked spots on the leaves, as the disease progresses lesions develop thin brown borders and the centers may become brittle and crack. The remaining can survive on crop debris for more than a year. Scouting plants during cool wet conditions, crop rotation, removal of crop debris, and timely application of fungicide could manage the disease.

Target leaf spot
[Corynespora cassiicola, Corynespora melonis (Pleosporales: Corynesporasaceae)]
Angular yellow spots appear on older leaves; as the disease progresses, the spots enlarge and become circular with light brown centers and dark margins; as lesions mature, they turn gray and drop out leaving holes in the leaves; if fruits become infect- ed early in their growth then the blossom end may darken and become shriveled. The fungus can survive on plant debris for periods over 2 years; disease emergence is favored by periods of high humidity and temperature. Plant resistant varieties; apply appropriate protective fungicide; sanitize equipment regularly.

Verticillium wilt
[Verticillium dahlia (Hypocreales: Incertae sedis)]
Symptoms generally appear after fruit set; chlorotic leaves which develop necrotic areas; leaves collapsing; symptoms only on one side of the vine; discoloration of vascular tissue in roots. The fungus can survive in the soil for many years; disease emergence is favored by cool or mild weather in Spring. Do not plant in areas where other susceptible crops have been grown previously; delay planting until temperatures are warmer.

Phytophthora blight
[Phytophthora capsici (Peronosporales: Peronosporaceae)]
The disease affects all stages and all parts of the crop. On seedlings, the pathogen causes damping-off symptoms with rotting of the stem near the soil line and the mature plants exhibit crown rot symptoms.
This causes wilting and death of the plant. Infected fruits have water-soaked lesions. Rain and overhead irrigation favor the spread of disease. Disease-free seeds, crop rotation, and fungicides can help in managing the disease.

**Pythium fruit rot** (Cottony leak)  
*Pythium* spp. (Peronosporales: Pythiales)  
Initially, symptoms occur on the fruit parts that remain in touch with the soil. These spots spread very fast to a large portion of fruit resulting in soft and necrotic areas. White fungal mass resembling the tufts of cotton can be seen in the infected area. The pathogen spreads via water and soil particles. Excessive soil moisture increases the disease occurrence. Use of mulch help in managing the disease.

**Scab**  
*Cladosporium cucumerinum* (Capnodiales: Mycosphaerellaceae)  
Symptoms occur on leaves as small water-soaked or pale green spots. The damaged leaves appear cracked. Under favorable conditions, the pathogen produces a dark, velvety layer of spores on the cavities. The pathogen overwinters on the seed, in crop debris, and soil. Removal and destruction of infected parts and plant debris, use of disease-free seeds and resistant varieties, crop rotation helps in managing the disease.

**Angular leaf spot**  
*Pseudomonas syringae* (Pseudomonadales: Pseudomonadaceae)  
Small water-soaked lesions on leaves expand between leaf veins and become angular in shape; in humid conditions, lesions exude a milky substance which dries to form a white crust on or beside lesions; as the disease progresses, lesions turn tan and may have yellow/green edges; the centers of the lesions dry and may drop out leaving a hole in the leaf. Spread through infected seed, splashing rain, insects, and movement of people between plants; bacterium overwinters in crop debris and can survive for 2.5 years. Use disease-free seed; do not grow plants in the field where cucurbits have been grown in the previous 2 years; protective copper spray may help reduce the incidence of disease in warm, humid climates; plant resistant varieties.

**Bacterial leaf spot**  
*Xanthomonas campestris* (Xanthomonadales: Xanthomonadaceae)  
Initial symptoms of the disease are the appearance of small water-soaked lesions on the undersides of the leaves which lead to the development of yellow patches on the upper leaf surface; the lesions become round and angular and may be mistaken for angular leaf spots; the centers of the lesions become thin and translucent and lesions become surrounded with a wide yellow halo. Bacteria are spread via infected seeds. Use disease-free seed; do not grow plants in the field where cucurbits have been grown in the previous 2 years; avoid overhead irrigation, water plants from the base instead to reduce the spread of bacteria.

**Aster yellows**  
*Aster yellows phytoplasma*  
Symptoms include yellow foliage, prolifically growing shoots, disfigured flowers. The disease is transmitted by leafhoppers. Weeds function as a reservoir for phytoplasma. Removal of infected plants, weed control, control of leafhoppers helps manage the disease.
viruses and insect pests

**VIRAL DISEASES**

**Cucumber green mottle mosaic virus (CGMMV)**

This virus is spread primarily by seeds. Crumpled, bleached, and chlorotic leaves are major symptoms. Different strains show varied symptoms and all varieties are susceptible to the virus. Some resistant varieties are available in Canada and Europe. Disease-free seeds, destruction of infected plants, proper sanitation of farm tools helps manage the disease.

**Cucumber mosaic virus (CMV)**

Symptoms include stunted plants, deformed foliage and flowers, discolored fruits, green vein banding, mottled leaves and is spread by aphids and parasitic weeds, *Cucurbita* spp. Controlling aphids could manage the disease. Some resistant varieties are available. Use of certified disease-free seed is advisable.

**Watermelon mosaic virus (WMV)**

Although symptoms vary widely depending on the cultivar, some common ones are green mosaic pattern, green vein banding, chlorotic rings, and disfigured leaves. This virus is spread by over 20 aphid species. Managing aphids could manage the disease.

**INSECT PESTS**

**Melon fruit fly**  
*Bactrocera cucurbitae* (Diptera: Tephritidae)

The melon fruit fly is a polyphagous insect and is widely distributed in the tropical, subtropical, and temperate region of the world. Adults lay eggs just below the epidermis of fruit. The maggots feed inside the pulp of fruits and cause punctures and feeding tunnels that provide entry points for various bacteria and fungi and the infested fruit start rotting. Pupation takes place in the soil. Use of the sex attractant cue-lure traps, field sanitation, bagging, and resistant varieties are useful to manage this pest. Natural enemies include parasitoids *Opius fletcheri*, *Fopius arisanus* (Hymenoptera: Braconidae); nematode, *Steinernema carpocapsae*; and fungi, *Rhi- zoctonia solani*, and *Gliocladium virilens*.

**Whitefly**  
*Bemisia tabaci*, (Hemiptera: Aleyrodidae)

Whiteflies are small sap-sucking insects. Feeding damage causes whitening and wilting of the under surface of newly emerging leaves. Whiteflies also vector viruses such as Cucurbit yellow stunting disorder virus, Cucurbit chlorotic yellows virus, beet pseudo yellows virus, and lettuce infectious yellows virus. Whiteflies also excrete honeydew which promotes the growth of sooty mould on leaves and hinders photosynthesis. Use of yellow sticky traps, crop rotation, mulching, floating row covers, non-infested transplants, cover crops, and good field sanitation.

**Parasitoids**  
*Encarsia formosa*, *E. luteola* (Hymenoptera: Encarsia), and *Eretmocerus californicus* (Hymenoptera: Aphelinidae); fungi *Verticillium lecanii*, *Beauveria bassiana* and *Paecilomyces fumosoroseus*, predatory bugs (Hemiptera: Miridae, Anthocoridae), beetles (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae, Coniopterygidae), spiders (Araneae) and predaceous mites (Acarina: Phytoseiidae) are useful.

**Aphids**  
*Myzus persicae, Aphis gossypii, Macrosiphum euphorbiae* (Hemiptera: Aphididae)

Heavy infestation by these sap-sucking insects causes yellow and distorted leaves with necrotic spots. Aphids also secrete honeydew that encourages the growth of sooty mould on the plants. Use tolerant varieties, reflective mulches to deter aphids, insecticidal soaps, neem products are advisable.

**Melon thrips**  
*Thrips palmi* (Thysanoptera: Thripidae)

It is a polyphagous pest that attacks cucurbits, eggplant, bean, and other crops. Nymphs and adults feed on plants and pupation takes place in soil. Thrips damage results in flower bud drop. Stunting of terminal shoots, and curled and scarred fruits. Predatory bugs, *Orius* spp. (Hemiptera: Anthocoridae) are known to feed on thrips.
insect pests and nematodes

Pumpkin beetles
[Aulacophora foveicollis, A. similis, A. lewisii, A. frontalis, A. coffeae] (Coleoptera: Chrysomelidae)
Adults cause serious damage feeding on leaves and flowers. Heavy infestations can cause mortality of seedlings. Eggs are laid near the base of the plant. Grubs tunnel into the roots, causing them to swell, be discolored, misshapen and growth retarded. Pupation takes place in the soil.

Cucumber moth
[Palpita (=Diaphania) indica] (Lepidoptera: Pyralidae)
Eggs are laid singly on the lower surface of leaves and the caterpillars mostly feed on the leaves. They rarely attack fruits. Pupation takes place inside the rolled leaves. Parasitoids, Apanteles machaeralis, Apanteles taragamae, Dolichogenidea stantoni, (Hymenoptera: Braconidae), Elasmus indicus (Hymenoptera: Elasmidae), and Goniozus sensorius (Hymenoptera: Bethylidae) have been reported attacking caterpillars of this pest.

Root-knot nematode
[Meloidogyne spp. (Tylenchida: Heteroderidae)]
This is a highly polyphagous nematode and all varieties are susceptible. Major symptoms include stunted growth, pale green to yellow leaf coloration. Due to infestation, the water uptake is reduced and plants wilt. Single and clumps of wart-like galls can be observed on roots. Crop rotation, soil fumigation, the practice of the fallow period, and the use of neem cake could be useful to manage the nematodes.
cucumber IPM techniques

• Soil sanitation to manage soil-borne diseases and soil-inhabiting insect pests.

• Organic soil amendments and mulching to manage soil-borne diseases and nematodes.

• Soil application of neem cake, to control nematode infestation.

• Application of fertilizers and compost inoculated with Trichoderma spp., neem cake, and Vesicular Arbuscular Mycorrhiza (VaM) to improve nutrients available to the crop, priming the plant’s own defenses and reducing the incidence of nematodes and other plant diseases.

• Select high-yielding locally preferred cucumber variety that is resistant or moderately resistant to diseases.

• Grow transplants in mesh-covered seedbeds to prevent aphids, and whiteflies.

• Soil/seed application of bacteria and fungi such as Pseudomonas fluorescens, Penicillium griseofulvum, Penicillium oxalicum, Bacillus subtilis, Paecilomyces lilacinus, Gliocladium virens, and Trichoderma spp. reduce the severity of diseases and nematodes.

• For seed treatment with beneficial fungi and bacteria use gum arabic to increase efficacy.

• The use of seedling trays and coconut pith medium reduces contamination.

• Crop rotation with non-host crops helps in reducing the incidence of soil-borne diseases.

• Setting up yellow sticky sheets in fields helps to reduce populations of aphids, thrips and whiteflies. Pheromone traps can be used for fruit flies.

• Use of neem-based formulations for managing aphids, whiteflies, and other pests.

• Bacillus thuringiensis is effective against lepidopteran pests.
Maize, or corn, is a cereal grain first domesticated in southern Mexico about 10,000 years ago. Maize is a staple food in many parts of the world, with the total global production surpassing that of wheat or rice. It is consumed directly and is also used for corn ethanol, animal feed, and other maize products, such as corn starch and corn syrup. There are seven maize groups based on the structure of the grain: flint maize, dent maize, sweet (and super sweet) maize, floury maize, popcorn, waxy maize, and pod corn. The U.S. is the world’s largest maize producer. In Asia, the maize crop is rotated with other cereal crops such as rice, barley, millet, as well as crops like pulses and oilseeds. In African countries, maize is successfully rotated with sorghum, millet, cassava, cowpea, soybean, potatoes, and other vegetables. Maize is a cold-intolerant crop with a shallow root system. The crop depends on soil moisture and is a more water-efficient crop than others. Maize is most sensitive to drought at the time of silk emergence when the flowers are ready for pollination. The constraints to maize production are biotic and abiotic. The most important abiotic constraints are low soil fertility, drought, and soil erosion. Among biotic constraints, insect pests, diseases and weeds are foremost. These pests are grouped into three categories – field pests, field-to-store pests, and store pests. Different parts of the maize crop (seed, root, foliage, tassel, stem, ear, and grain) are susceptible to different insect pests. The list of major insect pests includes lepidopteran pests (cutworms, armyworms, earworms, borers, grain moths), coleopteran pests (wireworms, grubs, weevils), and sap-sucking insect pests that serve as vectors of diseases (leafhoppers and aphids). Major diseases include leaf/sheath blight, downy mildew, ear/stalk rot, rust, anthracnose, maize lethal necrosis disease, and Maize streak virus. Maize also faces a major problem of weeds including several species of grasses, broadleaf plants, and sedges.
Ear rots

[Fusarium verticillioides (=Fusarium moniliforme) (Nectriaceae), Diplodia maydis (=Stenocarpella maydis) (Diaporthaceae)]

Fusarium verticillioides is a seed-borne endophyte in maize. It is very common and also difficult to eliminate. Warm dry weather early in the growing season, followed by wet weather during the development of the cob increases the infection. Fusarium verticillioides is associated with high levels of disease-causing mycotoxins—fumonisins—on infected kernels. These mycotoxins are harmful to humans and cattle.

Diplodia maydis causes ear rot, stalk rot, and seedling blight of corn. Corn is the only host for this pathogen. Ear rots overwinter on the diseased stalk and ear tissues that have not been buried. In the spring, the fungus reproduces on the plant debris and produces spores that are moved by rain and wind to the new crop. The fungal spores land on the plant and commonly infect at the base of the ear if sufficient water is available. Symptoms of ear rot begin as tan spots on the base of the husk and ear leaf, which expand over the ear, and at later stages white fungal growth spreads over and between the kernels. Resistant varieties are also available. Crop rotation is very useful to manage ear rots because the fungus survives poorly overtime on infested debris.

Leaf spot

[Cercospora zeae-maydis (Mycosphaerellaceae), Phaeosphaeria maydis (Physodermataceae)]

Cercospora zeae-maydis only infects corn. This disease causes considerable yield loss in most maize-growing areas of Africa. The disease is usually associated with an increase in the maize production area, continuous planting of maize on the same plot of land year after year, and the use of minimum tillage practices. The initial symptoms of grey leaf spots are small, dark, moist spots that are encircled by a thin, yellow radiance. Spots are initially brownish and yellow and later on turn into grey color due to the production of grey fungal spores. Phaeosphaeria maydis also causes small, pale green lesions scattered over the leaf surface. With maturation, lesions dry and develop dark brown margins. Lesions also coalesce and become irregular in shape and blight the entire leaf. Maize plants on the edges of the fields are more prone to this disease. This disease is pronounced in cold conditions. Spores overwinter on the diseased stalk and ear tissues that have not been buried. In the spring, the fungus reproduces on the plant debris and produces spores that are moved by rain and wind to the new crop. The fungal spores land on the plant and commonly infect at the base of the ear if sufficient water is available. Symptoms of ear rot begin as tan spots on the base of the husk and ear leaf, which expand over the ear, and at later stages white fungal growth spreads over and between the kernels. Resistant varieties are also available. Crop rotation is very useful to manage ear rots because the fungus survives poorly overtime on infested debris.

Smut

(Sphacelotheca reiliana) (Microbotryaceae)

Smut is distributed in Asia, Africa, the Americas, and Europe and invades plants during emergence or at the seedling stage through soilborne teliospores. It grows systemically with the meristem and does not get transmitted from one plant to the other. Infection is visible at a late stage of plant development on tassels and ears (large smut galls) of the maize plant. The infected corn ear looks very small and teardrop shaped, and the cob looks empty. A relatively low percentage of infection in the fields (10%) can cause significant yield reduction (about 80%). Once the infection occurs, there are no effective treatments for reducing or eliminating the damage on affected plants. Head smut spores can survive in the soil for several years. Balanced soil fertility should be maintained, with an emphasis on sufficient nitrogen. Tolerant hybrids are available and hybrids with fast emergence are less prone to head smut infection.

Southern leaf blight (Helminthosporium maydis), Pioneer.com
Maize streak virus (MSV)  
(Geminiviridae)  
MSV occurs throughout Africa and causes severe damage. It is transmitted by several leafhopper species. This also infects several species of Poaceae. MSV causes continuous parallel chlorotic streaks on leaves, with severe stunting of the affected plant, hence, failure to produce complete cobs or seed. During epidemic years, MSV can cause 100% yield loss.

Maize lethal necrosis disease (MLN)  
This disease is an emerging disease in sub-Saharan East Africa. This disease is caused by coinfection of maize with Maize chlorotic mottle virus (Tombusviridae) and one of several viruses from the Potyviridae (Sugarcane mosaic virus, maize dwarf mosaic virus, Johnsongrass Mosaic virus or Wheat streak mosaic virus). The coinfected viruses act synergistically. Infection results in frequent plant death or severely reduced or negligible yield. Multiple maize crops per year, maize thrips (Frankliniella williamsi), susceptible maize crops, and soil and seed transmission play significant roles in development and spread of this disease. Best measures to manage this disease still need further studies.

Southern leaf blight of maize  
[Helminthosporium maydis (=Cochliobolus heterosporus, Bipolaris maydis)  
(Pleosporaceae)]  
This disease is found around the globe and during the summer season it is considered the most important disease of maize.  
*Helminthosporium maydis* infects leaves, sheaths, ear husks, ears, cobs, shanks, and stalks. Infected seedlings wilt and die within a few weeks of planting. Symptoms vary depending on the race of leaf blight. Lesion color can be tan with brown, red borders or yellow-green or chlorotic halos. The shape of lesions can be diamond, elliptical or spindle-shaped. Resistant/tolerant hybrids are available (RML-4/RML-17 and RML-32/RML-17). Destruction of infected crop residue is useful.

**VIRAL DISEASES**

**Maize dwarf mosaic virus (MDMV)**  
(Poatviridae)  
MDMV is a serious maize pathogen and epidemic worldwide causing about 70% loss in corn yield globally. MDMV is a single-stranded RNA virus and is transmitted in a non-persistent manner by several aphid species. MDMV infected plants exhibit mosaic patterns, which occur near the lower part of the youngest leaves. Other symptoms include mottling spots and irregular necrotic lesions. MDMV infected plants show a delay in flowering as well as a poor grain set and fill.
**Spotted stem borer**

*[(Chilo partellus) (Lepidoptera: Crambidae)]*

Adults of the stem borer lay eggs on lower surfaces of 3-5 leaf stage maize plants. The first symptom appears when the rolled leaves unfurl and a series of pinholes and papery windows become visible. Afterward, larvae move out of the whorl, bore upward in the developing stalk, and feed on the meristem, and the leaf whorl dries up causing ‘dead heart.’ Stem borers become problematic in spring and summer plantings when temperatures and insect reproduction rates are high. Yield losses of 26-80% in different agro-climatic regions are reported. *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae), *Cotesia flavigula* (Hymenoptera: Braconidae), *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae), and *Tetrastichus howardii* (Hymenoptera: Eulophidae) are known to occur on stem borers.

**Pink stem borer**

*[(Sesamia inferens) (Lepidoptera: Noctuidae)]*

Larvae of pink stem borer feed inside the leaf sheath on the epidermal layer of the first three leaf sheaths. The presence of excreta and circular ring-like cuts on lower internodes are symptoms of this pest. This is the most important pest during winter and causes yield losses of about 80%. The plant dries due to the creation of dead hearts. *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae) and *Cotesia flavigula* (Hymenoptera: Braconidae) are known to attack this insect pest.

**Fall armyworm**

*[(Spodoptera frugiperda) (Lepidoptera: Noctuidae)]*

It is an invasive pest in Asia and Africa and attacks all stages of the plant. Early instar larvae feed in and around the whorl leaves, and scrape and skeletonize the upper epidermis. It also creates pinhole damage. Late instar feeding causes severe defoliation and feeding during the reproductive stage causes damage to tassels, ears, and kernels. Monitoring, pheromone traps, neem, *Bacillus thuringiensis*, *Metarhizium anisopliae*, Beauveria bassiana, *SfNPV*, *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae), *Telenomus remus* (Hymenoptera: Platygastridae), and *Habrobracon* (Bracon) *hebetor* (Hymenoptera: Braconidae) can help manage this pest.

**Army worms**

*[(Spodoptera litura, Mythimna separata) (Lepidoptera: Noctuidae)]*

Younger larvae of these pests feed in groups and gradually spread out. This pest creates a windowpane effect and causes a papery appearance by scraping the leaf surfaces. There are polyphagous pests that can cause heavy damage to the maize crop. Neem, pheromone traps, as well as *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae), *Telenomus remus* (Hymenoptera: Platygastridae), *Cotesia* sp., and *Bracon* sp. (Hymenoptera: Braconidae) are known to occur on these pests.

**Asian maize borer**

*[(Ostrinia furnacalis) (Lepidoptera: Pyralidae)]*

It is distributed throughout Asia. Maize plants are attacked 3-4 weeks after sowing. Larvae feed on the leaf tissue, tunnel into the midrib, and move to stalks and ears. Parasitoids affecting this pest include *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae), *Brachymeria obscurata* (Hymenoptera: Chalcididae), and *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae).

**White grubs**

*[(Phyllophaga spp. and Cyclocephala spp.) (Coleoptera: Scarabaeidae)]*

The white grubs are about an inch long with a brown head and have a curved “C”...
shaped body. White grubs eat roots and attack stems, causing plants to wither and die. Stunted, wilted, discolored, or dead seedlings may emerge when white grubs attack, and farmers may see gaps in rows where plants fail to emerge. Possible damage can be assessed by digging and examining the root system of the plant.

**Cutworm**

*[(Agrotis ipsilon) (Lepidoptera: Noctuidae)]*

Cutworm is a polyphagous chewing insect that feeds on leaves and tender stems of young plants below and above the ground. One larva per 10 plants can cause considerable damage. Poison baits (wheat bran, groundnut cake, water) are useful to assess and manage the population below ground.

**WEEDS**

Maize crop suffers several weeds, which cause high loss of yield. Some of the most common species in Asia and Africa are *Striga* sp., *Echinochloa colona*, *Eleusine indica*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Panicum coloum*, *Ageratum conyzoides*, *Galinsoga parviflora*, *Phyllanthus niruri*, *Commelina benghalensis*, *Polygonum dichotomiflorum*, *Aeschynomene indica*, *Cyperus rotundus*, *Cyperus esculentus*, and *Cyperus iria*.

**NEMATODES**

**Maize cyst nematode**

*[Heterodera zeae (Heteroderidae)]*

Found in Asia and America. This nematode-infested plants exhibit poor growth, are stunted, and are pale green. Crop rotation with non-cereal crops (soybean, cotton and vegetables), deep summer ploughing, intercropping of maize with soybean, and use of resistant/tolerant hybrids help manage the problem.

**Root-knot nematode**

*[Meloidogyne incognita (Heteroderidae)]*

Early symptoms of root nematodes include severely reduced growth of the plants coupled with extensive leaf yellowing. The occurrence of this nematode can cause yield loss.
• Maintain weed-free field to avoid alternate hosts of pests and diseases.

• Sowing of crops at the proper time at optimum seed rate enables the crop to cover the ground and hence avoid weeds.

• Select insect/disease-resistant varieties.

• Select pure high-quality certified seeds free of disease, weed seeds, and insect damage.

• Treat seeds with *Trichoderma/Pseudomonas* to protect from soil-borne diseases.

• Crop rotation helps to manage weeds, insect pests, nematodes, and diseases.

• Use balanced soil fertility, avoid high level of N and low level of K to manage diseases.

• Set up pheromone traps for lepidopteran pests to monitor and to take up timely interventions.

• For conservation biological control, preserve parasitoids *Trichogramma* spp., (such as *Trichogramma chilonis*, *Trichogramma dendrolimi*, *Trichogramma evanescens*, *Trichogramma mwanzae*), *Trichogrammatoides armigera* (Hymenoptera: Trichogrammatidae), *Cotesia flavipes*, *Bracon chinensis* (Hymenoptera: Braconidae), *Tetrastichus ayyari* (Hymenoptera: Eulophidae), *Telenomus remus* (Hymenoptera: Braconidae), *Apanteles marginiventris*, *Microplitis* sp. (Hymenoptera: Braconidae), *Campopleis flavidus* (Hymenoptera: Ichneumonidae), and tachinid flies (Diptera), and predators ladybird beetles, carabid beetles, spiders, earwigs, dragon flies, preying mantids, pentatomid bugs, reduviid bugs, robber flies, rove beetles, wasps, and lace wings.

• If pesticide applications are necessary, apply biopesticides e.g. *Metarhizium* sp., *Beauveria bassiana*, *Bacillus thuringiensis*, Nomuraea rileyi, NPV (nuclear polyhedrosis virus), nematode (*Steiner nema carpocapsae*), and botanical insecticides (e.g. neem).

• Release of egg parasitoids, *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae) and *Telenomus remus* (Hymenoptera: Platygastridae), and larval parasitoids *Habrobracon hebetor* and *Cotesia icipe* (Hymenoptera: Braconidae) for control of cutworms and other caterpillar pests.

• Plant *Brachiaria* grass in the borders to attract and *Desmodium* within the maize field to repel stem borer moths.

• Both foliar and seed treatments are used to protect maize crops. Need-based pesticide application at the various stages of growth to manage diseases and insect pests. Use pesticides as last option and do not use pesticides with the same mode of action repeatedly. Follow the recommended dose of the manufacturer. Consult local extension officials for pesticide selection.
Pearl millet (*Pennisetum glaucum*) is a crop native to Africa. Pearl millet is usually grown without irrigation or fertilizers. This crop is grown in well-drained soils and is well-adapted to poor, dry, and infertile soils; therefore, it is critically important for food security in some of the world’s hottest, driest cultivated areas where soils are tough and rainfall is low. With climate change affecting weather and rainfall patterns, it is becoming an increasingly important crop. Pearl millet is the most widely cultivated millet and India and Africa are its largest producers. It is mostly grown in the drier areas of India and Sahelian Africa. Other countries where pearl millet is grown include the United States and Puerto Rico. The short-cycle cultivars (85–95 days to maturity) are the most widely cultivated compared to long-cycle (120–130 days maturity) cultivars and can be grown under irrigation in rotation with higher-value crops. Pearl millet can tolerate higher temperatures but does not tolerate long consecutive drought periods. Pearl millet is used in making porridge and millet flour is used to make flatbread. Millets have about 73% carbohydrates, 11% protein, 9% water, and 4% fat. In addition to being an important food source, pearl millet has several medicinal applications (it is gluten-free, can reduce cholesterol and blood sugar levels, and can address iron and zinc deficiency). The stems can be used for building construction and as roof thatch. In India and Africa, millet is also used as fodder. Pearl millet can be used as a cover crop to suppress soil-borne diseases and to increase soil organic matter. Major abiotic stresses include long periods of drought, cold weather, and increased nitrate levels. Younger pearl millet plants encompass greater levels of nitrate, which could be harmful to cattle. Major insect pests include several species of stem borers, shoot fly (*Atherigona approximata*), pearl millet head-miner (*Heliocheilus albipunctella*), and grain midge (*Geromyia penniset*). Major diseases include cercospora leaf spot (*Cercospora pennisi*), rust (*Puccinia substriata*), pearl millet downy mildew (*Sclerospora graminicola Sacc.*), ergot (*Claviceps fusiformis*), and smut (*Tolyposporium penicillariae*).
Fungal Diseases

Ear Diseases

Ergot [Claviceps fusiformis, Claviceps africana] Frederickson (Hypocreales: Clavicipitaceae)
Ergot is a fungal disease of inflorescences and symptoms include the appearance of viscous creamy-pink exudations on the flowering heads. Later, it forms a hard-brown spiky structure called sclerotia. These sclerotia contain alkaloids that are toxic for humans. Ergot also reduces grain yields. Initial infection is from spores produced from sclerotia in the soil or crop debris. Secondary infection is from the spores produced in the honeydew. Once the stigmas have been pollinated they rapidly wither and are no longer available as the infection route for the ergot fungus. Heavy rain at flowering time washes down pollen, extending the period at which the stigmas are available for infection as well as providing ideal conditions for germination and sporulation of the ergot fungus. Host plant resistance, avoidance, and sanitation are the best way to manage this problem.

Pearl millet downy mildew [Sclerospora graminicola, (Peronosporales: Peronosporaceae)]
Mildew is a fungal disease of foliage. The symptoms include chlorosis at the base of a leaf that then extend towards the tips of the leaves. White powdery development also occurs on the leaves. Inflorescences of infected tillers have the characteristic green-ear symptoms where the grain is replaced by whip-like vegetative structures. When infected at the early stage, plants may die. This fungus infects the growing point of each tiller when the leaf and panicle tissues are being formed. Primary infection is from oospores that live in the soil and secondary infection happens by the sporangia on the undersides of infected leaves. To manage the problem, proper disposal of infected plants should be done and removal of diseased plants or tillers at the first sign of disease could minimize secondary spread. Resistant varieties are available for managing this disease.

Rust [Puccinia substriata (Pucciniales: Puccinaceae)]
This is a foliar fungal disease and symptoms include small yellow or white raised spots on upper and lower leaf surfaces. More spots occur on the lower side of the leaves and at later stages spots become bigger and red-brown surrounded by a yellow halo. Rust spores survive in crop residue in soil and spread through the wind. To manage the disease, disease-resistant varieties are available.

Foliar and stem diseases

Cercospora leaf spot [Cercospora penniseti (Capnodiales: Mycosphaerellaceae)]
This fungal disease causes small, dark lesions with grey centers on leaves. Lesions can also be present on stems, and in rainy weather, spores also become visible. High temperatures coinciding with periods of high humidity increases this disease incidence. To manage this disease, resistant varieties, weed management, crop rotation, sanitation are practiced.

Rust

[Saccosporium graminicola (Peronosporales: Peronosporaceae)]
Mildew is a fungal disease of foliage. The symptoms include chlorosis at the base of a leaf that then extend towards the tips of the leaves. White powdery development also occurs on the leaves. Inflorescences of infected tillers have the characteristic green-ear symptoms where the grain is replaced by whip-like vegetative structures. When infected at the early stage, plants may die. This fungus infects the growing point of each tiller when the leaf and panicle tissues are being formed. Primary infection is from oospores that live in the soil and secondary infection happens by the sporangia on the undersides of infected leaves. To manage the problem, proper disposal of infected plants should be done and removal of diseased plants or tillers at the first sign of disease could minimize secondary spread. Resistant varieties are available for managing this disease.

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Smut

[Tolyposporium penicillariae (Ustilaginales: Cintractiaceae)]
Symptoms of this inflorescence disease include the development of sori on the ears. These sori appear as sacs and are initially green and later on turn dark brown or black. These sacs are filled with black spores of smut. The mature spores are released from the sori when the crop is threshed and then get mixed with seeds of non-infected florets, and are the source of infection for the subsequent crop. Resistant cultivars are available.
INSECT PESTS

**Foliage and stem pests**

**Stem borers**

**Pearl millet stem-borer** [*Coniesta ignefusalis* (Lepidoptera: Crambidae)] (Africa only)

**Spotted stem borer** [*Chilo partellus*, *Chilo sacchariphagus* (Lepidoptera: Crambidae)] (Africa and Asia)

**Pink stem borer** [*Sesamia inferens* Walker, *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae)] (Africa and Asia)

**White stem borer** [*Saluria inficita* (Lepidoptera: Pyralidae)]

The stem borer complex causes major damage to pearl millet in all growing areas. These borers attack plants from 4-week-old through grain maturity. In general, after egg hatching, early instar larvae enter the leaf whorl and feed on soft tissues. Due to this feeding damage, leaves show pinhole damage after they unfold. Afterward, larvae move out of the whorl, bore upward in the developing stalk, feed on the meristem, and the leaf whorl dries up, causing ‘dead heart.’ Later instar larvae bore into stems, forming grass-filled tunnels. The most prominent stem borer in Africa is [*Coniesta ignefusalis*]. It affects mostly late-planted or late maturing material. The first-generation larvae cause dead heart and stand loss, while the second and third cause lodging, disruption of the vascular system and inhibition of grain formation. Yield losses range from 15% to total crop failure due to *C. ignefusalis*. Stem borers become problematic in spring and summer plantings when temperatures and insect reproduction rates are high. Stem borer complex could cause yield loss to pearl millet crop. Use of pheromone bait traps to monitor adult stem borers is recommended. Control measures should be taken as soon as stem borers are detected.

**Management strategies** include use of resistant varieties and neem products early in the season before the larvae bore into the stem of the plant. Use of natural enemies *Trichogramma* spp., (Hymenoptera: Trichogrammatidae) and *Telenomus* spp. (Hymenoptera: Platygastridae), and *Habrobracon* (*Bracon*) *hebetor* (Hymenoptera: Braconidae) and *Tetrastichus atriclavus* (Hymenoptera: Eulophidae) are effective in managing populations of *C. ignefusalis*.

**Shoot fly** [*Atherigona approximata* (Diptera: Muscidae)]

This is a major seedling pest, especially in the Indian subcontinent. In India, it causes 50% grain loss and 60% dry fodder yield loss during cold weather. It attacks seedlings and boot leaf stage of pearl millet and damages the earhead. It causes dead hearts in young plants and chaffy grains in mature crop. Increasing seed rate and removing shoot fly damaged seedlings at time of thinning is helpful in managing this pest.

Not much is known in terms of biological management.

**Leaf beetles** [*Lema planifrons* (Coleoptera: Chrysomelidae)]

They feed on leaves of seedlings by scraping their chlorophyll portions, resulting in light colored spots, bleached appearance of leaves. Infestations are sporadic and associated with prolonged period of drought.

**Grasshoppers**

[*Kraussaria angulifera*, *Oedaleus senegalensis* (Orthoptera: Acrididae)]

Both species cause major yield loss in pearl millet by feeding on the foliage and stem in Africa. By chewing they cause mechanical damage to the plant and the entire plant dies. Entomopathogenic fungus *Metarhizium anisopliae* and *Beauveria bassiana* can manage grasshoppers.

**Green bug** [*Schizaphis graminum* (Hemiptera: Aphididae)]

Aphids are polyphagous insects that suck sap, colonize in large numbers and secrete honeydew. Honeydew induces sooty mold on plants, hindering photosynthetic capacity. They produce several generations in a season. Both nymphs and adults suck sap from young leaves and whorls and cause yellowing, distortion of leaves, wilting, and death of plants. Damaged plants produce shriveled chaffy grain.

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Earhead pests

Pearl millet head-miner \( [Heliocheilus albipunctella \ (Lepidoptera: \ Noctuidae)] \)
This pest causes damage to earheads of pearl millet in the Sahelian region of Africa. Larvae feed on panicle and prevent grain formation. Young larvae perforate glumes and eat away flowers. Later larval instars cause characteristic damage in form of spiral mines by cutting floral peduncles. Depending on climate, soil type, crop cultivar, plant density, plant growth stage, dispersal, and abundance of natural enemies, pest level varies. Late planting or maturing varieties to avoid moth flight period coinciding with vulnerable stages of head development, light traps, resistant and tolerant varieties, and the egg parasitoid \( Trichogrammatoidea \ armiger \) (Hymenoptera: Trichogrammatidae) and larval parasitoid, \( Habrobracon \ hebetor \) (Hymenoptera: Braconidae) are effective in managing this pest.

Grain midge
\( [Geromyia \ pennseti \ (Diptera: \ Cecidomyiidae)] \)
This pest could cause 90% yield losses in parts of Africa and India. Larvae of grain midge feed on developing grain and form white pupal cases attached to tips of spikelets. Due to feeding, glumes become empty. Early attack results in complete withering of ovary while late attack may cause lesions on formed seeds. Plants have a blasted appearance. The life cycle is completed in 2 weeks and 4 or 5 generations may occur in a single season, with successive generations overlapping.

Blister beetles
\( [Psalydolytta \ fusca, \ Psalydolytta \ vestita, \ Decapotoma \ affinis \ (Coleoptera, \ Meloidae)]; \) and chaffer beetles \( [Rhyniptia \ infuscata \ (Coleoptera, \ Rutelinae)] \)
Blister beetles are common in Africa, feed on pollen, and directly affect grain filling. Nymphs and adults feed on developing grain, causing distortion and shrinking of grains. The chafer beetle \( R. \ infuscata \), is responsible of sporadic losses ranging from 37 to 57% on millet in Niger. They feed on florets and stamens, resulting in formation of empty spikelets.

Soil inhabiting pest

White grub
\( [Holotrichia \ consanguinea \ (Coleoptera: \ Scarabaeidae)] \)
White grub is a pest of pearl millet in India. Larvae feed on roots, causing seedlings to wither and die, and patches of dead seedlings in the field become visible. Pesticide applications are recommended in areas with high pressure and during outbreaks.
pearl millet IPM techniques

OTHER THREATS

**Top rot**
(*Fusarium verticillioides*=*Fusarium moniliforme*)

- Maintain a weed-free field to avoid alternate hosts of pests and diseases.
- Select insect/disease-resistant varieties.
- Treat seeds with *Trichoderma* spp./*Pseudomonas fluorescens* to protect them from soil-borne diseases.
- Set up pheromone traps for stem borers to monitor and to take up timely interventions.

**Zonate leaf spot**
(*Gloeocercospora sorghi*)

- If pesticide applications are necessary, apply biopesticides e.g. *Metarhizium anisopliae*, *Metarhizium rileyi*, *Beauveria bassiana*, *Bacillus thuringiensis*, and botanical insecticides (e.g. neem).

**Seedling blight**
(various fungi)

**Head mold**
(various fungi)

**Striga or Purple witchweed**
(*Striga hermonthica*)

- Release of egg parasitoids, *Trichogramma* spp, *Trichogrammatidea armigera* (Hymenoptera: Trichogrammatidae) and *Telenomus* sp. (Hymenoptera: Playgastridae), and larval parasitoid *Habrobracon hebetor* (Hymenoptera: Braconidae) for control of lepidopteran pests.

**TECHNIQUES**

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Rice is an annual, self-pollinated, and semi-aquatic plant and belongs to the family Poaceae. Asian rice (Oryza sativa; subsp. japonica and indica), African rice (Oryza glaberrima), and wild rice (genus Zizania) are known to be consumed by humans. Oryza sativa subsp. indica was first domesticated in India, whereas Oryza sativa subsp. japonica was domesticated in China. Rice is the most important food crop in the world and is a staple food across Asia and becoming important in Africa and Latin America. The traditional method of cultivating rice is flooding the direct-seeded fields with or after transplanting the young seedlings and is called irrigated rice production. Rice is also grown in the rainfed lowland, in mountains or plateaus, and the deep water. About 90 percent of rice production occurs in Asia. Although rice consumption and demand are increasing around the globe, especially in Asia, stability in rice production in Asia depends on social and political stability. Climate change plays a major role in rice production in Asia. Irrigated rice area provides major production, but it is hard to increase irrigated rice area because of the problems of soil salinity, high cost of development, water scarcity, alternative and competing uses of water, and environmental concerns of the emission of greenhouse gases. Overall major issues faced in rice production in Asia are variety development, a decline of productivity, declining production resources due to deteriorating soil health, increasing costs of production, post-harvest losses, and abiotic and biotic stresses. Major diseases are Rice blast, Sheath blight, Brown spot, Sheath rot, Seedling blight/Stem rot, Bacterial blight, and Tungro Virus. Major insect pests are Rice mealybug, Stem borers, Rice gall midge, Leafhoppers and Planthoppers, Leaf folder, Case worm, Rice bugs, Rice hispa, and Rice swarming caterpillar. Rice root-knot nematode is also a major problem in Asia.
**Bacterial blight**  
[Xanthomonas oryzae pv. oryzae] (Xanthomonadales: Xanthomonadaceae)  
This is a vascular disease resulting in systemic infection of rice. It causes tannish grey to white lesions along the veins. Although the first symptoms are observed at the tillering stage, the incidence increases with plant growth and peaks at the flowering stage. There are two different phases, the leaf blight phase and the kresek phase. In kresek stage, the leaves turn pale yellow and wilt; hence, it is the most destructive stage. In leaf blight phase, yellow lesions with wavy margins appear on leaf blades. In rainy seasons it can cause 50 percent yield loss. Resistant varieties play a major role in the management of this disease.

**Sheath blight**  
[Sarocladium oryzae (Hypocreales: Sarocladiaceae)]  
This disease develops irregular spots or lesions, with dark reddish-brown margins and gray center on leaf sheath, which causes discoloration of the sheath. Enlargement and coalescence of lesions often covers the entire leaf sheath, infected panicle gets rotten, and white powdery growth can also be seen. The disease appears late during the growing season of the rice crop and can cause yield losses from 20 to 85 percent.

**Seedling blight/Stem rot**  
[Sclerotium oryzae (Magnaporthales: Magnaporthaceae)]  
This disease is most noticeable in rice fields during the latter stages of maturity. On leaf sheath, it initially causes black, rectangular lesions with distinct angular borders. At later stages, the lesions become larger and penetrate deep into the culm. Maximum injury to the stem occurs at harvest, resulting in lodging of plants and harvesting to become difficult. The presence of tiny, black sclerotia at the base of the stem indicates its presence.

**Fungal Diseases**

**Rice blast**  
[Magnaporthe oryzae/Pyricularia grisea/ Magnaporth grisea (Magnaporthales: Magnaporthaceae)]  
Rice blast is the most serious of the rice diseases because it infects all plant growth stages. This disease attacks all parts of the plant except the leaf sheath and spreads rapidly. Depending on the site of the symptoms, this disease is referred to as leaf blast, collar blast, node blast, and neck blast (or neck rot). It stunts or kills seedlings and tillering plants and also reduces the number of panicles and lowers grain weight and quality. Collar blast can also damage the entire leaf blade and the panicle.

**Sheath blight**  
[Rhizoctonia solani] (Cantarellesa: Ceratosidaceae)]  
The characteristic symptoms of this disease are water-soaked, circular/oblong/ellipsoid/ovoid or even irregularly elongated discolored lesions on the leaf sheath at or above the water level in lowland and at ground level in upland fields. This disease does not affect seedlings; however, under very high humidity and at favorable temperatures, even the seedlings may get wilted. No resistance variety is available.

**Brown spot**  
[Bipolaris oryzae (Helminthosporium oryzae)]  
It is a seedborne disease. Leaf spots can be observed shortly after seedling emergence and continue to develop until maturity. Damage from the brown spot is particularly noticeable when the crop is produced in nutritionally deficient soil conditions and is indicative of a soil fertility problem.

**Bacterial Disease**

**Rice Tungro**  
(Rice tungro bacilliform virus and Rice tungro spherical virus)  
Leaf discoloration is a characteristic feature of these viral diseases, which begins from the leaf tip and extends down to the lower leaf portion. Infected leaves also show mottled or striped appearance and stunting. Infection to rice plants reduces tillering, delays flowering, and can delay maturity. Panicles also become sterile or have partially filled grains and are covered with dark brown blotches. At the early crop growth stage this disease can cause 100 percent yield loss. Symptoms of the disease are usually absent at the early growth stage. To manage this problem, use of resistant varieties is important.

**Viral Disease**

Note: The majority of rice viruses occur in Asia (about 12 viruses) and most of them are transmitted by leaf hoppers and plant hoppers. Rice grassy stunt virus, Rice ragged stunt virus, and Rice Tungro are major issues in Asia.
Rice mealybug

[Brevicoryne brassicae (Hemiptera: Pseudococcidae)]

This pest is a foliar feeder on rice in Asia. Severe drought, bad drainage, and poor soil increase infestation. Presence of alternate hosts in fields or on field bunds, presence of ants, and irrigation water helps migration of the bug. Nymphs and adults suck sap from the rice stem, which results in smaller leaves, yellowing, abnormal tillering, and stunted plants. When heavily infested, either no panicles are formed, or they do not fully emerge from the boot and may dry off. Lady beetles Coccinella septempunctata, Menochilus sexmaculatus, and Harmonia axyridis (Coleoptera: Coccinellidae); parasitoids Ceraphron sp (Hymenoptera: Ceraphronidae), Adelencyrtus sp. (Hymenoptera: Encyrtidae); Anatrichus pygmaeus and Mepachymerus ensifer (Diptera: Chloropidae) are reported to attack this mealybug.

Insect Pests

Stem borers

[(yellow stemborer (Scirpophaga incertulas), white stemborer (Scirpophaga notata), striped stemborer (Chilo polychrysus), dark-headed stemborer (Chilo suppressalis) (Lepidoptera: Crambidae); pink stemborer (Sesamia inferens) (Lepidoptera: Noctuidae)]

Damage caused by these stem-boring species is similar. Early instars do not cause severe damage when they feed on leaves and within leaf sheaths. However, when caterpillars feed within the culm on growing point and vascular tissue, they cut off the growing portion of the plant from the base. At the vegetative stage of plant development, feeding of larvae results in plants failing to produce panicles (dead hearts). Even after damage, rice is capable of partly or fully compensating for losses of tillers by putting forth additional tillers. Several native predators, parasitoids (braconid, eulophid, mymarid, scelionid, chalcid, pteromalid, ichneumonid wasps, ants, lady beetles, staphylinid beetles, gryllid, green meadow grasshopper, and mirid, phorid and platystomatid flies, carabid and lady bird beetles, chloropid fly, gerrid and pentatomid bugs, ants, and mites, earwigs, birds, asilid fly, dragonflies, damselflies, and spiders) and entomopathogens (Steinernema carpocapsae, Heterorhabditis bacteriophora, Metarhizium anisopliae and Beauveria bassiana) are known to manage stemborers.

Rice gall midge

[(Orseolia oryzae) (Diptera: Cecidomyiidae)]

Infestation leads to silver shoot or induction of gall, which causes an onion leaf appearance. Newly hatched grey-white maggots move between the leaf sheath and the stem and approach the opening point of the apical or side bud at a node. Next, the maggot feeds inside the developing bud, which is a zone of differentiation for new tillers. A hollow chamber (gall) formation happens around the maggot and as the maggot feeds, gall enlarges at base and elongates. Instead of development of panicle, gall development occurs. Crop loss ranges from 10-100 percent. Predatory mite Amblyseius imbricatus (Parasitiformes) attacks eggs. Maggot parasitoids Platygaster oryzae (Hymenoptera: Platygasteridae) and Obtusiclava oryzae (Hymenoptera: Pteromalidae) and pupal parasitoids, Neanastatus oryzae and N. cinctiventris (Hymenoptera: Eupelmidae) are known.

Brown planthopper

[Nilaparvata lugens (Homoptera: Delphacidae)]

This pest is polyphagous and distributed throughout Asia. The weed Leersia hexandra functions as a primary alternate host. It infests all stages of plant growth. Both nymphs and adults of this pest damage rice plants by sucking sap and removing translocating nutrients, hence, reducing net photosynthesis. At early infestation, round yellow patches appear, which soon turn brownish on the plants. This condition is called ‘hopperburn.’ Feeding and egg-laying sites expose plants to fungal and bacterial infections. Honeydew excreted by the nymphs and adults at the base of the plants induce growth of sooty mold. Nilaparvata lugens also transmits the virus diseases, such as Rice ragged stunt virus (RRSV) and Rice grassy stunt virus (RGSV).

Increased nitrogen fertilizer use has been suggested to benefit N. lugens’s population growth.
White-backed planthopper
[Sogatella furcifera, (Homoptera: Delphacidae)]
This pest causes ‘hopper-burn.’ Outbreaks are reported in Asia. Bionomics and symptoms resemble brown planthopper. Nilaparvata lugens eggs are parasitized by Anagrus optabilis (Hymenoptera: Encyrtidae), Paracentrobia andoi (Hymenoptera: Trichogrammatidae), and Tetrastichus formosam (Hymenoptera). Mirid bug Cyto- rhinus lividipennis (Hemiptera: Miridae), and predatory mite Amblyius sp. (Acarina: Phytoseiidae) prey on the eggs. Nymphs and adults of N. lugens are parasitized by Elenchus japonicus (Strepsiptera), Echthrodelphax bicolor (Hymenoptera: Dryinidae), and nematode Hexamerminus sp. Fungal pathogen Beauveria bassiana infects them. This pest does not transmit diseases.

Case worm
[Nymphula depunctalis (Lepidoptera: Pyralidae)]
This pest is a problem in lowland at the vegetative stage of rice. Due to its semi-aquatic mode, it can cause severe damage in paddy fields with standing water. Infestation is more severe in dwarf, compact, heavy tillering, and high-yielding varieties and late maturing rice crop. Larvae feed on tender leaves and make cases as they grow. Damage is caused by larvae feeding and cutting off the leaf and creating a ladder-like appearance on leaves. Damaged plants become stunted and produce fewer tillers and smaller panicles, resulting in delayed maturity. Trichogramma japonicum, T. chilonis, and T. minutum (Hymenoptera: Trichogrammatidae) are egg parasitoids of rice caseworm. Predators such as spiders, birds, and adult dragonflies/damsel flies are dominant natural predators of caseworm adults, while aquatic beetle larvae, aquatic bug nymphs and adults, and ants feed on caseworm larvae and snails feed on caseworm eggs.

Stink bug
[Nezara viridula (Hemiptera: Pentatomidae)]
Both nymphs and adults cause damage but adults are particularly damaging. Although they feed on other parts of the rice plant, they prefer grains at the milk stage and even ripening grain. Diffused brown spots caused by the exudation of the sap mark points of insertion of mouthparts. In severe cases of infestation, most grains in a field are sucked empty. Damage during the dough stage causes discoloration of mature grain and causes weakness in the kernel. Such rice has lower milling quality or is pecky rice of inferior grade. Predators such as grasshopper, Conocephalus longipennis (Orthoptera: Tettigoniidae) and assassin bug Nabis stenoferus (Hemiptera: Nabidae) feed on this pest. Trissolcus basalis (Hymenoptera: Platygastridae) is used in several countries to manage this pest. Beauveria bassiana also infects this pest.

Leaf folders
[Cnaphalocrois medinalis, Marasmas patnalis and Marasmas exigua (Lepidoptera: Crambidae)]
Leaf folders are especially in areas of high nitrogen fertilizer use. Larvae fold leaves longitudinally and fasten leaf margins with stitches of silken threads. Larvae feed by scraping green mesophyll from within folded leaves. Feeding greatly reduces the photosynthetic ability of infested rice plants and heavily infested leaves dry up and appear scorched. Damaged leaves serve as entry points for fungal and bacterial infections. Several species of Diptera (e.g., Megaselia spp. and Argyrophylax spp.), Hymenoptera (Goniozus spp., Trichogramma spp., Apanteles spp., and Bracon spp.), Coleoptera (Chlaenius spp. and Coccinella spp.), Orthoptera (Anaxipha spp. and Metioche spp.), Araneae (Argiope spp., Pardosa spp., and Tetragenatha spp.), and nematode (Aganemnion spp.) have been reported as parasitoids and predators in Asia. Microbial insecticide Bacillus thuringiensis is effective against larvae.

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Rice bug
[Leptocorisa acuta, L. chinensis, L. variicornis, L. oratorius (Hemiptera: Alydidae)]
This pest is found in all rice environments but is more prevalent in rainfed wetland or upland rice. Adjacent woodlands, extensive weedy areas near rice fields, and staggered rice planting provide a favorable condition for this pest. Both nymphs and adults are destructive to the crop, but damage by nymphs is more severe. This pest completes 1–2 generations on grassy weeds before migrating to rice fields. A small number of adults usually appear in rice fields as soon as the plants start flowering. When about 80 percent of the grains have ripened, the adults migrate to fields having rice plants of less maturity. Nymphs and adults feed by inserting mouthparts at the meeting points of glumes (lemma and palea). This insertion point has a white exudate that turns into a brown spot. Due to removal of stored assimilates from the developing grains, grains either remain unfilled or partially filled with damage symptoms. Feeding damage causes grain discoloration or pecky rice, which is more liable to break during milling. This pest is more prevalent in rainfed wetland or upland rice. Adjacent woodlands, extensive weedy areas near rice fields, and staggered rice planting provide a favorable condition for this pest. Both foliar and seed treatments are used to protect rice crops. Need-based pesticide application at the budding, flowering, and/or podding stage is helpful to manage diseases and insect pests.

Rice hispa
[Dictadispa armigera (Coleoptera: Chrysomelidae)]
Grubs and adults feed on rice plants. Adults scrape the upper surface of leaf blade, often leaving only the lower epidermis. Damaged areas appear as white streaks parallel to the midrib. Tunneling of the grubs between the two epidermal layers results in irregular translucent white patches starting from ovipositional sites near the leaf tip and extending toward the base of the leaf blades. Affected parts of leaves usually wither off. In severe infestations, leaves turn whitish and membranous and dry off. Braconid wasps Bracon hispae, Bracon sp., Campyloneurus sp., and Macrocentrus sp. (Hymenoptera: Braconidae) are known to parasitize grubs, as well as pupal parasitoids Eupteromalus sp., Trichomalopsis apanteloctena, and Serothenus sp. (Hymenoptera: Pteromalidae).

Rice swarming caterpillar
[Spodoptera mauritia (Lepidoptera: Noctuidae)]
This pest causes severe damage to rice plants in nursery beds. It appears suddenly in masses and moves like an army from field to field, making seedbeds or direct-seeded fields look grazed. Generally, a transplanted crop is not severely affected. They migrate from field to field and extensive losses are often caused within a week. The absence of standing water in the fields facilitates migration. Egg parasitoids, Telenomus nawaii (Hymenoptera: Platygastridae) and larval parasitoids Archytas cirphis and Peribaea orbata (Diptera: Tachinidae) are known to manage this pest.

Rice root-knot nematode,
[Meloidogyne graminicola (Nematoda: Meloidogynidae)].
It is a major pest in upland (rainfed) and lowland (irrigated) rice, and in deep water ecosystems. It forms characteristic knots or galls on root tips of rice seedlings, which retards growth of root tips. Due to infestation, seedlings fail to elongate above rising floodwater and 20–80 percent yield loss occurs in flooded fields.

Bakanae
(Fusarium moniliformae) Bacterial grain and seedling rot (Burkholderia glumae), False smut (Ustilaginoidea virens), Rice gundhi bug (Leptocorisa acuta), Mealybug (Ripersia oryzae), Armyworm (Mythimna seprata), Plant hoppers and leaf hoppers (Nephotettix virescens, Nephotettix apicalis, Nephotettix nigropictus, Recilia dorsalis Ceeadela spectra), Termites (white ants), Rice panicle mite (Steneotarsonemus spincki), Blue beetle (Leptispa pygmoea), Stem borer (Chilo partellus sp).
• Raise pre-crop of sun hemp or other green manure crops and incorporate 45 days old crop in the soil during land preparation.

• Set up plastic sheet barrier strips and traps around the field for rodent control.

• Till, remove weeds, and level the field to maintain an even level of water to minimize weed growth.

• Clean bunds (levees) to remove alternate hosts of pests and diseases.

• Select insect/disease resistant varieties.

• Clean bunds (levees) to remove alternate hosts of pests and diseases.

• Select pure high-quality seeds free of disease, weed seeds, and insect damage.

• Apply seed sorting by floatation.

• Treat seeds with Trichoderma/Pseudomonas to protect from soil-borne diseases.

• In direct sown rice, crop should be sown in lines at recommended spacings to facilitate inter-weeding operations.

• The normal spacing of transplants rice plants should be 30–36 hills/m² (depending on the duration of the variety).

• Remove disease infected plants and insect infested plant parts in the nursery before transferring to the main field.

• Seedlings should be free of weed seedlings at the time of transplanting.

• Mechanical weed control methods applied at 2–3 weeks after sowing and a second time at 4–6 weeks, if necessary.

• No pesticide spray period for the first 40 days after sowing or transplanting.

• Plant marigold, sesame, or vegetables on the bunds, which serve as nectar and pollen sources to parasitoids and predators.

• Release of egg parasitoid Trichogramma japonicum and T. chilonis @100,000/ha on appearance of leaf folder, stemborer egg masses as biocontrol agents (both natural enemies parasitize the pest egg masses).

• Need-based pesticide application at the various stages of growth to manage diseases and insect pests. Use pesticides as last option, and do not use pesticides with the same mode of action. Follow the recommended dose of the manufacturer. Consult local extension officials for pesticide selection.
Chickpea (Cicer arrietinum L.) (Fabaceae) is an annual legume (pulse crop) of the family Fabaceae. It is commonly known as garbanzo bean, Egyptian pea, and gram, or Bengal gram. Based on seed color, chickpea is also classified as ‘Desi’ or ‘Kabuli’ types. Desi chickpea has a pigmented (tan to black) seed coat and small seed size (greater than 100 seeds/28 gms), whereas Kabuli or garbanzo bean has white to cream-colored seed coats and size ranges from small to large (50–100 seeds/28 gms). Chickpea originated in the Middle East and got domesticated in Southeast Asia. Currently, chickpea is grown in about 57 countries in Asia, Australia, Middle East, North America, South America, Africa, and Europe. Major producers of Chickpea are India, Australia, Myanmar, Ethiopia, Turkey, Russia, Pakistan, Iran, Canada, USA, Mexico, Malawi, Morocco, and Syria. In 2019, India shared 70% of global chickpea production. The chickpea plant is a self-pollinating, small bush with a height ranging from 30 to 60 cm. Chickpea crop performs best with the long, warm growing season and is usually grown as a rainfed, cool-season crop in semiarid regions. Well-draining, sandy loam soils with a pH 5.0–7.0, and annual rainfall of 600–1000 mm are best for this crop. It is sown in early spring and is harvested in late summer or early autumn. Chickpea seeds inoculationed with Rhizobium ciceri ensures effective nodulation and nitrogen-fixing activity. Chickpea contains 25-29% protein, 65% carbohydrates, a small percentage of fat content, and is consumed fresh as green vegetables, boiled, parched, fried, and roasted. Major abiotic stresses for this crop are drought, salinity, waterlogging, high temperature, and frequent frost, which can limit the growth and productivity of chickpea. Major biotic stresses include diseases such as ascochyta blight (Ascochyta rabiei), fusarium wilt (Fusarium oxysporum), sclerotinia stem rot (Sclerotinia sclerotiorum), damping-off (Pythium spp.), dry root rot (Macrophomina phaseolina), phytophthora root rot (Phytophthora megasperma); and insects such as pod borer (Helicoverpa armigera), adzuki bean beetle (Callosobruchus chinensis), cutworm (Agrotis ipsilon), beet armyworm (Spodoptera exigua), chickpea leafminer (Liriomyza cicerina) and black aphid (Aphis craccivora).
Botrytis gray mold
[Botrytis cinerea (Helotiales: Sclerotinia-ceae)]
It affects aboveground plant parts including leaves, stems, flowers, pods, and seeds. The most affected parts are growing tips and flowers. Symptoms initially occur as water-soaked lesions that later turn gray and dark brown. A series of cool, wet summers are ideal for its development. Affected leaves and flowers turn into rotting masses. Severely infected leaves wilt and fall and ultimately plants can die. Flower drop is also common due to this disease, which leads to poor pod formation and low grain yields. Botrytis cinerea is also associated with seedling disorders (soft rot) of chickpea. Infected seeds are shriveled and discolored. Bacteria, Pseudomonas fluorescens, and Penicillium griseofulvum, and the fungi Trichoderma spp. reduce the severity of botrytis gray mold.

Downy mildew
[Peronospora ciceris (Peronosporales: Peronosporaceae)]
It infects all the aerial plant parts and causes curled, twisted leaves, and dwarfed tips. Cool and humid conditions are favorable. Initial symptoms include white mycelial patches on the lower leaf surfaces and chlorotic to yellow spots on the upper surface. Infected plants remain stunted and form bushy apical growth. Late planting and resistant germplasm lines help manage this disease.
**Alfalfa mosaic virus**
Chickpea plants become chlorotic and stunted and often have chlorotic and necrotic shoot tips. Plants die prematurely. It is transmitted by at least 14 different aphid species, the common one being *Acyrthosiphon pisum* (Hemiptera: Aphididae).

**Bean yellow mosaic virus**
It causes malformation, mottling, and stunting in plants. Infected leaves get twisted and curled. Flowering and pod formation is reduced and small seeds are produced by the infected plants. This is transmitted by several aphid species in a nonpersistent manner.

**Cucumber mosaic virus**
It causes chlorosis, leaf malformation, and stunting in plants. Leaflets show a mild mosaic and reddening of leaf margins. This virus is transmitted by several aphid species.

**Pea seed-borne mosaic virus**
It causes filiform leaves, indistinct mosaic patterns, mottling, chlorosis, reddening, necrotic lesions, a proliferation of stems, and abortion of pods. It is transmitted by several aphid species.

**Chickpea chlorotic dwarf virus**
It is the predominant cause of yellowing and stunting diseases of cool-season food legume crops in Ethiopia. The disease is also called chickpea stunt disease. It is vectored by leaf hoppers (*Empoasca devastans, Orosius albicinctus*) (Hemiptera: Cicadellidae).

**Dry root rot**
*Macrophomina phaseolina* (Botryosphaeriales: Botryosphaeriaceae)
It is a soil-inhabiting organism capable of infecting chickpea at any crop stage, but most commonly infects chickpea at post-reproductive stage in dry and warm regions. Yield loss information is not available. Symptoms of this disease include drooping of petioles and leaflets on the tips, dark, rotten tap roots, presence of gray fibrous fungal threads on the taproot, and dry root. High temperature and low moisture are favorable for this disease. Resistant cultivars are available. Seed treatment with *Trichoderma* spp., *Streptomyces* sp., *Pseudomonas* sp., *Penicillium oxalicum*, *Pythium oligandrum*, and *Bacillus* spp. can manage fusarium wilt of chickpea.

**Phytophthora root rot**
*Phytophthora medicaginis* (Peronosporales: Peronosporaceae)
Symptoms of this disease can develop from seedling emergence to near maturity. It causes wilting, chlorosis, and rapid death of the plant. Taproots of the infested plant are girdled by brown and black zones of the rotting process. Warm and wet soil conditions are favorable for this disease. Resistant varieties are available to manage this disease. Late planting to avoid wet and soils could be useful. Biological seed treatments with *Trichoderma harzianum, Penicillium oxalicum*, *Pythium oligandrum, Pseudomonas fluorescens*, and *Bacillus* spp. help manage this disease.

**VIRAL DISEASES**

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INSECT PESTS

Pod borer

[Helicoverpa armigera (Lepidoptera: Noctuidae)]

_Helicoverpa armigera_ is a major issue in Asia, Africa, and Australia. The young larvae cause damage to the leaves scraping the surface of leaflets and feeding on flowers, while older larvae feed on foliage and are more damaging to pods. The adults are active at night and lay hundreds of eggs individually on the underside of leaflets. The last instar drops to the soil to pupate. Pheromone traps are available for adult _H. armigera_ monitoring and population peak prediction. Natural enemies include _H. armigera_ nucleopolyhedrosis virus (HaNPV), _Trichogramma chilonis_ (Hymenoptera: Trichogrammatidae), _Telenomus_ spp. (Hymenoptera: Platygastridae), _Microplitis demolitor_, _Apanteles marginiventris_, _Bracon kitcheneri_, _Microgas- ter_ spp., _Microplitis_ spp. (Hymenoptera: Braconidae), _Campoletis flavicincta_, _Hyposoter annulipes_, and _Ophion flavidus_ (Hymenoptera: Ichneumonidae), _tachinid flies (Diptera: Tachinidae), and predators_ _Bros gross punctatus_ (Coleoptera: Carabidae) and _Lygryllus bimaculatus_ (Orthoptera: Gryllidae). Entomopathogenic fungus (_Metarhizium_ sp.), nematode (_Steinernema carpocapsae_), and nuclear polyhedrosis virus are effective in managing this pest.

Cutworm

[Agrotis ipsilon (Lepidoptera: Noctuidae)]

Cutworm is polyphagous and spread around the globe. The larvae feed on the leaves, stems, and roots of the plant. The older larvae cut the plant above the root zone. Weeds in and around the crop are major oviposition sites. The sporadic nature of cutworm populations makes preventive treatments futile. One way to control cutworm is to broadcast a poison bait prepared with wheat bran, cotton, or groundnut cake, and moistened with water. Natural enemies recorded include parasitoids _Trichogramma_ spp. (Hymenoptera: Trichogrammatidae), _Apanteles marginiventris_, _Bracon kitcheneri_, _Microgaster_ spp., _Microplitis_ sp. (Hymenoptera: Braconidae), _Campoletis flavicincta_, _Hyposoter annulipes_, and _Ophion flavidus_ (Hymenoptera: Ichneumonidae), _tachinid flies (Diptera: Tachinidae), and predators_ _Bros gross punctatus_ (Coleoptera: Carabidae) and _Lygryllus bimaculatus_ (Orthoptera: Gryllidae). Entomopathogenic fungus (_Metarhizium_ sp.), nematode (_Steinernema carpocapsae_), and nuclear polyhedrosis virus are effective in managing this pest.

Armyworm

[Spodoptera exigua (Lepidoptera: Noctuida-idei)]

This pest is widely distributed throughout the tropics and subtropics. This is a polyphagous pest. The larvae primarily feed at night and hide during the day and bury themselves into the soil for pupation. Pheromone traps are available for this pest. Release of egg parasitoids, _Trichogramma_ spp. (Hymenoptera: Trichogrammatidae) and _Telenomus remus_ (Hymenoptera: Platygastridae), can help control armyworms and other caterpillar pests.

Aphids

[Apis craccivora and Acrthysiphon pism (Hemiptera: Aphiididae)]

Aphids feed on several grain legumes. The action threshold is 1-2 aphids per leaf and 9-13 aphids per sweep. They suck the sap and colonize in large numbers and secrete honeydew. They cause sooty mold on the plants and also vector several viruses. _Apis craccivora_ is a vector of various virus diseases of chickpea, such as _Alfalfa mosaic virus_, _Cucumber mosaic virus_, and _Bean yellow mosaic virus_. Aphids usually infest chickpea at the podding stage, but if they infest at an early stage, then control is necessary. Natural enemies recorded are predators _Coccinella septem- punctata_, _C. transversalis_, _Cheilomenes sexmaculata_, _Menochlus sexmaculatus_, _Brumus suturalis_ (Coleoptera: Coccinellidae), chrysopids _Chrysoperla_ spp. (Neuroptera: Chrysopidae), and parasitoids _Trioxys indicus_ and _Lipolexis scutellaris_ (Hymenoptera: Braconidae). Yellow sticky traps are useful for monitoring aphids.

Green stink bug

[Nezara viridula (Hemiptera: Pentatomidi)]

Green stink bug is a polyphagous pest that sucks the sap from leaves, stems, and pods, and thus causes malformation and drying of plants. It causes heavy damage during the reproductive stage of the plant. Early planting, close spacing, and trap crops are used to manage this pest. The parasitoid _Trissolcus basalis_ (Hymenoptera: Platygastridae) is known to attack eggs of stink bug. Entomopathogenic fungi, _B. bassiana_, _M. anisopilae_, and _Paecilomyces lilacinus_ can manage this pest.
Parasitic crenate broomrape (Orobanche crenata), Egyptian broomrape (Orobanche aegyptiaca) (Orobanchaceae), and dodder (Cuscuta campestris) (Convolvulaceae) pose a serious problem in the Middle East. Field preparation, irrigation scheduling, careful harrowing, proper sowing, and crop establishment play an important role in the cultural management of weeds.

Alternaria blight (Alternaria alternata), Sclerotinia stem rot (Sclerotinia sclerotiorum), Collar rot (Sclerotium rolfsii), Pythium seedling and root rot (Pythium ultimum), Rhizoctonia seed, seedling, and wet root rot (Rhizoctonia solani), Verticillium wilt (Verticillium albo-atrum), Sclerotinia stem and crown rot (Sclerotinia sclerotiorum), Bacterial blight (Xanthomonas campestris), Bacterial root rot (Pseudomonas radiciperda), Bacterial stem canker (Pseudomonas andropogonis), Pink seed (Erwinia rhapontici), Faba bean necrotic yellow virus, Mastreviruses, Luteoviruses (yellowing viruses), Chickpea chlorotic stunt virus, Pea streak virus, Pea enation mosaic virus, Reniform nematode [Rotylenchulus sp. (Tylenchida: Hoplolaimidae)]

It causes patches of stunted chlorotic plants. Infected plants grow less vigorously.

Root-knot nematode [Meloidogyne spp. (Tylenchida: Heteroderidae)]

It has a wide host range and causes excessively branched and galled roots. It aids in Fusarium fungus entry into the roots.

Adzuki bean beetle
[Callosobruchus chinensis (Coleoptera: Bruchidae)]

This pest is an important cosmopolitan species of storage insects in many food legumes. The insect causes significant quantitative and qualitative damage and loss to chickpea. It is the larvae that feed and damage the seeds. The damage and yield loss caused by C. chinensis depend upon the condition of the environment, the higher temperature, and relative humidity that is conducive for the growth and development of this pest. The eggs of C. chinensis are laid on chickpea seeds and the larvae and pupae complete their development inside the grain. A single female may lay 100 eggs depending on the environmental condition. After hatching, the larvae bore into cotyledons where they develop into adults within a month. The adult exits the seed by making a hole.

Reniform nematode
[Rotylenchulus sp. (Tylenchida: Hoplolaimidae)]

It causes patches of stunted chlorotic plants. Infected plants grow less vigorously.

Root-knot nematode
[Meloidogyne spp. (Tylenchida: Heteroderidae)]

It has a wide host range and causes excessively branched and galled roots. It aids in Fusarium fungus entry into the roots.
• Soil sanitation to manage soil-borne diseases and soil-inhabiting insect pests.

• Soil application of neem cake, castor cake, mustard cake, and/or cotton cake to control nematode infestation.

• Sun-drying or solar treatment of seeds and application of bentonite dust to control seed-borne diseases and storage insect pests.

• Use of disease-free seeds.

• Seed treatment with bacteria and fungi such as *Pseudomonas fluorescens*, *Penicillium griseofulvum*, *Streptomyces pseudomonas*, *Bacillus* spp., *Bacillus subtilis*, *Trichoderma harzianum*, *T. viride*, *Paecilomyces lilacinus*, *Penicillium* spp., *Penicillium oxalicum*, *Gliocladium virens*, and *Pythium oligandrum* reduce the severity of diseases and nematodes.

• Use of gum arabic can increase the efficacy of *Trichoderma*.

• Seed treatment with *Rhizobium* sp. for root-nodule development.

• Use of tolerant and resistant varieties: Several resistant Desi and Kabuli germplasm lines have been identified for fusarium wilt by ICRISAT and ICARDA. Kabuli lines including ILC 9784, 9785, 9786; FLIP 86-93C, 87-38C, 87-33C, CA334.20.4, CA336.14.3.0, ICCI14216K, cultivars ICCV2—ICCV6; Sonora 80, Suruto 77; UC15, UC27; Genotype ICC-3230 show tolerance for downy mildew.

• Crop rotation and a 2-3-year period without chickpea production to reduce disease incidence.

• Changes in planting dates to avoid infection and infestation of some diseases and insect pests.

• Wide row spacing and canopy management to manage microclimate to avoid diseases.

• Weed management in the field to avoid alternate hosts for insect pests.

• Release egg parasitoids, *Trichogramma* spp. and *Telenomus remus*, for control of caterpillar pests.

• Foliar application of neem kernel extracts, and pyrethrins to control insect pests.

• Need-based safe pesticide application at the budding, flowering, and/or podding stage to manage diseases and insect pests.

• Prompt harvesting, proper drying before storage, storage hygiene to manage diseases and insect pests.

• Use of hermetic grain storage (deprive insects of oxygen) bags to manage storage pests.

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The common name, bean, is used to refer to plants belonging to several genera in the family Fabaceae. Common types of the beans are referred to as black beans, black-eyed peas, cannellini beans, great northern beans, kidney beans, lima beans, pinto beans, fava beans, adzuki beans, edamame beans, mung beans, cranberry beans, and navy beans. Beans are rich in protein and fiber and high in the amino acids, lysine, and methionine, making beans nutritionally complementary to cereals, which are deficient in these two amino acids. Beans are the main source of protein in a vegetarian diet. Major producers of dry beans are India, Myanmar, Brazil, and the USA. As a vegetable crop, beans are highly susceptible to arthropod pests and diseases. Several arthropod pests including bean fly, aphids, thrips, leafhopper, whitefly, leaf beetles, pod borers, pod bugs, spider mite, and broad mite cause significant damage to beans. For instance, up to 80% yield losses have been reported in various vegetable and grain legumes due to bean pod borer damage in Asia and Africa.
viruses & diseases

**VIRAL DISEASES**

**Bean common mosaic virus**
The typical symptoms appear as light and dark green mosaic patterns on the leaves. It is often accompanied by distortion and rolling of the leaves. It also leads to reduced plant growth, delayed maturity, and fewer pods. It has a worldwide distribution because of high rates of transmission through seeds. During the growing season, aphids transmit the virus as a secondary spread. It can also be transmitted mechanically and in pollen.

**Cucumber mosaic virus**
A very common and devastating viral disease transmitted by aphids. Systemic symptoms consist of prominent leaf epinasty and mosaic, confined to a few leaves. Other symptoms consist of leaf curl, green mottle, blistering, and a zipper-like rugosity along the main veins. Plants may recover, but the virus continues to replicate in symptomless tissue.

**Bean yellow mosaic virus**
Symptoms appear as a striking yellow-green mosaic on infected leaves, which becomes more intense as the leaves grow old. Infected leaves are often cupped downwards, show wilting, necrosis, distortion, and wrinkles. Infected plants show stunted growth and reduced production. Aphids commonly transmit the virus; however, the virus can be transmitted mechanically.

**Curly top virus**
Symptoms vary with growth stage, virus strain, and environmental conditions. Infected plants have thick and brittle leaves that turn dark green. Plants show puckering and wrinkling of leaves. Plants infected at the early stage are stunted and produce very few pods while plants infected at the later stage mature early and produce small pods. The virus is transmitted by leafhoppers.

**FUNGAL DISEASES**

**Bean anthracnose**
[Colletotrichum lindemuthianum (Glomerellales: Glomerellaceae)]
All above-ground plant parts are affected. Infected seeds have small, dark brown-black lesions on cotyledons. Red-brown spots and lesions also develop on stems, petioles, and leaves. The center of these lesions is light-colored and may show a pink ooze containing the conidia or spores of the fungus. A characteristic symptom appears on the lower surface of leaves, where veins turn red to purple and eventually black.

**Ascochyta Blight**
[Didymella rabiei = Ascochyta rabiei (Pleosporales: Didymellaceae)]
All above-ground plant parts are susceptible to this fungus. Brown lesions on seedlings may lead to damping off-like symptoms. Foliar symptoms appear as round brown-colored lesions without margins. As the lesions grow, black raised spots appear in concentric circles on these lesions. Pod infection results in poor seed set, discolored and small seeds. Infected seeds and crop residue are a source of survival for this fungus.

**Black root rot**
[Thielaviopsis basicola (Microascales: Ceratocystidaceae)]
Initial symptoms appear as brown necrotic lesions on below-ground stems and roots. These lesions often coalesce and form large black areas. In the case of severe infestation, stunting, premature defoliation, and plant death may occur.

**Charcoal rot/Ashy stem blight**
[Macrophomina phaseolina (Botryosphaerales: Botryosphaeriaceae)]
Infected seedlings develop small, irregular, black-colored sunken lesions on stems near the soil line. The infection spreads upwards, plant growing tips may be killed or the stem broken. These lesions have a defined margin and often contain concentric rings. Infection of older seedlings cause wilting, chlorosis, premature leaf fall, and death of plants. On older plants, several small black sclerotial bodies appear on the surface of stems. This “Charcoal dust” is characteristic evidence of this disease.

**Fusarium root rot**
[Fusarium solani (Hypocreales: Nectriaceae)]
Symptoms appear as narrow, longitudinal brick-red streaks on below-ground stems and roots. As the disease progresses, the streaks become dark and necrotic. In severe infections, the entire root system may be affected, resulting in stunted plants and premature leaf fall.

**Fusarium wilt**
[Fusarium oxysporium (Hypocreales: Nectriaceae)]
Symptoms usually appear on older plants and begin as yellowing and wilting of lower leaves. The symptoms progress upwards until the entire plant turns yellow and wilted. Plants infected at young stages are stunted. The vascular system becomes reddish-brown and sometimes the roots may appear swollen.

**Damping off and rot**
[Pythium spp. (Peronosporales: Pythiaceae); Rhizoctonia solani (Cantharellales: Ceratobasidiaceae); Thielaviopsis basicola (Microascales: Ceratocystidaceae)]
This disease can occur before or after plant emergence and can damage seedlings. In infected soils, seedlings may fail to emerge. While in post-emergence, seedlings are stunted, wilted, and topple over.

Bean common mosaic virus, Howard F. Schwartz, Colorado State University, Bugwood.org
Southern blight
[Sclerotium rolfsii = Athelia rolfsii (Atheliaceae)]
Initially, the symptoms appear as yellowing of lower leaves and slight darkening and water soaking of the stem just below the soil line. Lesions on the stem expand rapidly, girdling the stem and causing permanent wilting of plants. A white mat of mycelium develops on the stem and spreads into the surrounding soil. Characteristic, brown spherical sclerotia appear on the mycelium and the base of the plant.

White mold
[Sclerotinia sclerotiorum, S. trifoliorum (Helotiales: Sclerotiniaceae)]
Small, circular, dark green water-soaked lesions appear on leaves, branches, stems, and pods. These lesions grow and become slimy. Infected parts may develop a white cottony appearance, as the mycelium is often visible on the surface under favorable conditions. A characteristic diagnostic feature is the development of black irregular-shaped sclerotia. Entire branches or plants may be killed.

Common bacterial blight
[Xanthomonas campestris pv. phaseoli (Xanthomonadaceae)]
Symptoms appear as small water-soaked spots on leaves, which gradually become large, necrotic and surrounded by a yellow greenish-yellow ring. These lesions are found on margins and interveinal areas of the leaf. These lesions enlarge and result in defoliation or a burned appearance of the plant. Pods also show similar symptoms. Under favorable conditions, the lesions may have slimy bacterial ooze. Seeds from infected pods become shriveled and exhibit poor germination.

Bacterial brown spot
[Pseudomonas syringae pv. syringae (Pseudomonadaceae)]
Symptoms appear as small, circular, necrotic spots surrounded by yellow margins.

The spots enlarge and the centers of these spots may fall out, giving a ragged appearance to leaves. Water soaking and the slimy ooze are generally absent. Lesions on pods result in distorted pod growth.

Bean pod borer
[Maruca vitrata (Lepidoptera: Pyralidae)]
The larvae bore into pods and eat seeds. Pods have small dark entry holes and sometimes frass is visible. Larvae damage buds, flowers, and leaves by eating and webbing them together. Egg-larval parasitoid Phanerotoma syleata, and two larval parasitoids, Therophilus javanus and T. marucae (Hymenoptera: Braconidae) are effective against bean pod borer. Bacillus thuringiensis, Beauveria bassiana and Metarhizium anisopliae can be used to manage bean pod borer. Maruca vitrata multiple nucleopolyhedrovirus (MaviMN-PV) has been developed as a biopesticide.

Bean lycaenid
[Euclarsus cnejus (Lepidoptera: Lycaenidae)]
Larvae feed on pods and damage on pods is characterized by round holes and feeding on pod contents. The parasitoids Trichogramma bactrae (Hymenoptera: Trichogrammatidae) and Cotesia specularis (Hymenoptera: Braconidae) are effective against bean lycaenid.

Bean fly
[Ophiomyia phaseoli (Diptera: Agromyzidae)]
It is generally found in the petioles and stems. The larvae cause damage by mining the central core of the stem down to the shoot junction. Due to disruption in the vascular system, plants wilt and die. Opus phaseoli (Hymenoptera: Braconidae) and Eucoilidea sp. (Hymenoptera: Figitidae) are efficient parasitoids of bean fly.

Cowpea Aphid
[Aphis craccivora (Hemiptera: Aphididae)]
The aphid feeds on tender stems and terminal shoots, flowers, and pods. Heavy infestations can kill seedlings, cause flower drop and pod shriveling. Aphids suck sap from plants, resulting in yellowing, curling, and deformation of leaves. Continuous feeding by aphids leads to yellowing, wilting, and stunting of plants. Honeydew secretion leads to development of sooty mold. Aphids also vector several important viruses on beans including Bean common mosaic virus, Cucumber mosaic virus and others. The ladybird beetles (Menochilus sexmaculatus, Brumus sursalis, Harmonia dimidiate, and Coccinella septempunctata) (Coleoptera: Coccinellidae) and green lacewing (Chrysoperla carnea) (Neuroptera: Chrysopidae) are efficient predators of aphids. Beauveria bassiana and Metarhizium anisopliae can manage aphids.

Green stink bug
[Nezara viridula (Hemiptera: Pentatomidae)]
Feeding damage causes drying of shoots, shriveled pods and seeds. Egg parasitoids such as Ooencyrtus malayensis, Trissolcus basalis, T. rudus, T. mitsukurii, T. nakagawai, Telenomus cyrus, T. pacificus and T. comperei (Hymenoptera: Platygastridae) and the reduviid predator, Sycanus collaris keeps the stink bug under control.

Shield Bug
[Piezodorus hybneri (Hemiptera: Pentatomidae)]
Both nymphs and adults feed on pods, causing losses in fruit quality.

Garden looper
[Chrysopeleixis chalcites (Lepidoptera: Noctuidae)]
Larval feeding causes skeletonization of leaves. Sometimes, the larvae may also feed on buds.

Broad mite
[Polyphagotarsonemus latus (Acarina: Tarsonemidae)]
Damage is usually confined to the lower surface of leaves. Symptoms include leaf distortions, shortening of internodes, blistering, shriveling, curling and cupping of leaves, and leaf discoloration. Fruits are malformed and scarified.
Spider mites
[Tetranychus spp. (Acarina: Tetranychidae)]
Mites are cosmopolitan and polyphagous pests that feed on various vegetable crops and reduce yields. Mites cause yellow specks on leaves and produce webs on the leaf surface. Mites use web strands to disperse from one plant to another. Predatory mites such as Phytoseiulus persimilis and several species of Amblyseius, especially *A. womersleyi* and *A. fallacies* (Acarina: Phytoseiidae), can be used to control spider mites. Green lacewings are (*Mallada basalis* and *C. carnea*) (Neuroptera: Chrysopidae) also generalist predators of spider mites.

Leaf Miner
[Liriomyza spp. (Diptera: Agromyzidae)]
Larval feeding on leaves results in tunneling and the formation of whitish trails or mines on the leaves. It results in reduced photosynthesis and yield. Heavy infestation can kill plants. Several parasitoids keep the leafminer under control if synthetic pesticides are not misused.

Tomato fruit worm (corn earworm)
[Helicoverpa armigera (Lepidoptera: Noctuidae)]
Young larvae prefer to feed on leaves and flower buds but larger larvae feed on flowers and pods. Feeding holes filled with excreta are characteristic of larval damage. Severe damage leads to yield losses. *H. armigera* nucleopolyhedrovirus (HaNPV) is an effective agent to manage this pest. Several egg and larval parasitoids have been recorded.

Sweet potato whitefly
[Bemisia tabaci (Hemiptera: Aleyrodidae)]
Responsible for heavy crop losses worldwide, whiteflies damage beans by sucking and secreting sticky honeydew. Black sooty mold grows over the honeydew. Extensive feeding may result in stunting, poor growth, defoliation, and reduced yields. Natural enemies such as Encarsia sophia and *E. formosa* (Hymenoptera: Aphelinidae) are efficient parasitoids of this whitefly.

Beet armyworm
[Spodoptera exigua (Lepidoptera: Noctuidae)]
Armyworms feeding causes skeletonization of leaves. Mature larvae feed singly on leaves and bean pods. Damaged pods will have holes in the pod and beans. The egg-parasitoid Trichogramma chilonis (Hymenoptera: Trichogrammatidae), Telenomus remus (Hymenoptera: Platygastridae), and larval parasitoid Campoletis chlorideae (Hymenoptera: Ichneumonidae) can be used against this armyworm.

Beet armyworm, Whitney Cranshaw, Colorado State University, Bugwood.org

Root-knot nematode
[Meloidogyne spp. (Tylenchida: Heteroderidae)]
Root-knot nematodes have a wide host range and are most severe in warm areas with long growing seasons. Plants infected by root-knot nematodes are generally less vigorous and healthy. Symptoms of nutrient deficiency and diurnal wilting are visible on leaves due to the reduced efficiency of the root system. The presence of bead-like galls on roots is a characteristic of nematode presence.
• Before sowing, remove and destroy plant debris or infested plant material from the field to avoid fungal diseases. Remove weeds, which may serve as reservoir for diseases.

• Application of fertilizers and compost inoculated with *Trichoderma* spp., neem cake, and Vesicular Arbuscular Mycorrhiza (VaM) fungus improve the nutrients available to the crop, priming the plant’s defenses and reducing the incidence of nematode, fungal or other plant diseases.

• Selection of a high-yielding locally preferred bean cultivar that is resistant or moderately resistant to diseases such as *Bean yellow mosaic virus*, Ascochyta blight, Anthracnose, and insect pests like bean flies and bean thrips.

• Seed treatment with *Trichoderma viride* or *T. harzianum* fungi, and *Pseudomonas fluorescens*, and *Bacillus subtilis* bacteria protects seedlings from fungal and bacterial diseases, increases seedling vigor, and induces plant defense against pests.

• Crop rotation with non-host or less susceptible crops also helps in reducing the incidence of aphids, *H. armigera*, and diseases like bacterial brown spot, Ascochyta blight, and other soil-borne diseases.

• Setting up yellow sticky sheets in fields to reduce aphids and whiteflies. Blue sticky traps, help to reduce thrips. Pheromone traps can be used for *M. vitrata*, *S. litura* and *H. armigera*.

• Biopesticides *Bacillus thuringiensis*, *Beauveria bassiana*, and *Metarhizium anisopliae*, *Paecilomyces lilacinus*, and *Vetricillium lecani*, and botanical pesticide neem are effective against insect pests.

• Release of parasitoids, *Trichogramma* sp. (Hymenoptera: Trichogrammatidae) and *Telenomus* sp. (Hymenoptera: Platygastri- dae) for lepidopteran pests.

• Use of *Maruca vitrata multiple nucleopolyhedrovirus* (MaviMNPV) for *M. vitrata*.
Lentil (Lens culinaris) is an Old-World grain legume. Lentil is grown in Africa, Australia, Asia (Indian Subcontinent, Middle East, and West Asia), North America, North Africa, and Southern Europe. Two subspecies of lentil are cultivated in the world: macrosperma and microsperma. Macrosperma is found in the Mediterranean region and the New World (bigger seed size, 6–9 mm in diameter with yellow cotyledons) and microsperma (smaller seed size, 2–6 mm with red-orange cotyledons) is found on the Indian subcontinent and East Africa. Lentil is a major plant protein source that can provide moderate amounts of most essential amino acids and contains fair amounts of minerals, vitamins, and complex carbohydrates. This crop can fix atmospheric nitrogen and can sequester carbon, hence, can improve fertility and nutrient status of soil and further contribute to the sustainability of the agricultural production system.
**Fungus Diseases**

**Stemphylium blight**  
*Stemphylium botryosum (Pleosporales: Pleosporaceae)*  
It is a major problem in Asia and could cause more than 80% lentil crop loss. The host range of this disease is wide. It causes small, light-beige lesions that spread first on the upper canopy and then spread to the lower canopy. This causes leaf loss, and decreases plant biomass, seed size, yield, and germination rates. This is a serious problem. Several resistant and tolerant cultivars are available. A combination of intentional planting dates and resistant varieties is beneficial to manage this disease. In Asia, early sowing (mid-October) can significantly reduce this disease compared to when the crop is sown in December.

**Anthracnose**  
*Colletotrichum truncatum* (Glomerellales: Glomerellaceae)  
It causes irregularly shaped, light-brown necrotic, tan lesions on lower stems until plants have 8-12 nodes, at which point the plant appears blackish-brown. When leaflets in the lower canopy wilt and fall, then it indicates that this is a problem. This is a seed-borne disease and transmits from active plant infections or from spores lying dormant on foliage from past years. High humidity and temperatures are favorable for this disease.

**Rust**  
*Uromyces viciae-fabae* (Pucciniales: Pucciniaceae)  
It infects all aboveground plant parts. Yellowish, white pycnidia and aecial cups, which are single or in groups, are found on leaflets and pods in a circular pattern. When severely infected, complete crop failure occurs, producing small shriveled seeds. Hot and dry conditions are favorable. Rust is widespread all over the globe. Resistant cultivars are available to manage rust.

**Botrytis Gray mold**  
*Botrytis cinerea* (Helotiales: Sclerotiniaaceae)  
It affects aboveground plant parts including leaves, stems, flowers, pods, and seeds. The outbreak of this disease is reported in all growing regions. A series of cool, wet summers is ideal for its development. The first infection appears as dark green lesions on flowers, pods, or lower canopy, and then turns into pale, tan spots. Severely infected leaves wilt and fall and ultimately plants can die. Infected seeds are shriveled and discolored. Bacteria Pantoea agglomerans, Pseudomonas fluorescens, Penicillium griseofulvum, and the fungus Trichoderma spp. reduce severity of botrytis gray mold.

**Fusarium Wilt**  
*Fusarium oxysporum* (Hypocreales: Nectriaceae)  
This disease is found on almost all continents including the Americas, Africa, Europe, and Asia. It affects seedlings and reproductive stages. Wilting of top leaves, plant stunting, shrinking and curling of leaves, reduced root growth, and damaged tap root system are typical symptoms. In Asia, it is also reported at the seedling stage. Resistant and early maturing cultivars are available in several countries. Synergistic interaction between fusarium wilt and root-knot nematode (*Meloiodogyne spp.*) has been observed in some lentil cultivars, hence the presence of nematodes in the field significantly increases wilt incidence. Damage done by nematodes facilitates the disease’s infection on roots. Controlling one will help control of the other. Seed treatment with Trichoderma spp. and *Pseudomonas fluorescens* can be used to reduce nematode incidence.

**Collar rot**  
*Sclerotium rolfsii* (Aetheliales: Aetheliaceae)  
It causes yellowish brown discoloration, and rotting of infected regions. Dirty white-to-brown sclerotia are visible. This proceeds downward and causes root rot. Use of calcium fertilizers helps in reduction of this disease. Soil/seed application of Trichoderma harzianum, *T. viridae*, Bacillus subtilis, *Pencillium spp.*, and *Gliocladium virens* can be used to manage collar rot.

**Downy mildew**  
*Peronospora lentinis* (Peronosporales: Peronosporaceae)  
It infects all the aerial plant parts and causes curled, twisted leaves, and dwarfed tips. Cool and humid conditions are favorable. Infected plants remain stunted and form bushy apical growth. Resistant germplasm lines have been identified.
Green stink bug
[Nezara viridula (Hemiptera: Pentatomidae)]
Green stink bug is a polyphagous pest that sucks the sap from leaves, stems, and pods, and thus causes malformation and drying of plants. It causes heavy damage during the reproductive stage of the plant. Early planting and trap crops are used to manage this pest. The parasitoid Trissolcus basalis (Hymenoptera: Platygastridae) is known to attack eggs of stink bug. Entomopathogenic fungus, Beauveria bassiana, Metarhizium anisopilae, Paecilomyces lilacinus can be used to manage stink bug.

Lygus spp.
(Hemiptera: Miridae)
Lygus are a major pest in lentil production. Scouting is critical to spot the presence of lygus. Lygus bugs pierce tender leaves, stems, buds, petioles, and developing seeds. They cause serious damage to seeds and great economic damage due to chalky spot syndrome, which is characterized by pitted, crater-like depressions in the seed coat with or without a discolored chalky appearance. Economic thresholds have been established for lygus control. During bloom, one lygus bug for every three sweeps indicates action threshold. Entomopathogenic fungus, Beauveria bassiana, Metarhizium anisopilae, Paecilomyces lilacinus can be used to manage lygus bug.

Aphids
[Aphis craccivora and Acyrthosiphon pisum (Hemiptera: Aphididae)]
Aphids feed on several grain legumes. The action threshold is 1-2 aphids per leaf and 9-13 aphids per sweep. They suck the sap and colonize in large numbers and secrete powdery, sugary material. They cause sooty mold on the plants and also vector several viruses. *Aphis craccivora* is a vector of *Alfalfa virus, Cucumber mosaic virus* (CMV), and *Lentil tobacco streak virus*. Aphids usually infest lentil at the podding stage, but if they infest at an early stage, then control is necessary. Natural enemies recorded are predators including *Coccinella septempunctata, C. transversalis, Cheilomenes sexmaculatus, Menochilus sexmaculatus, Brunus sutralis* (all Coleoptera: Coccinellidae), chrysopids including *Chrysoperla* spp. (Neuroptera: Chrysopidae), and parasitoids including *Trioxys indicus* and *Lipolexis scutellaris* (Hymenoptera: Braconidae). Yellow sticky traps are useful to monitor aphids.

Reniform nematode
[Rotylenchulus sp. (Tylenchida: Heteroderidae)]
It causes filiform leaves, indistinct mosaic patterns, mottling, chlorosis, reddening, necrotic lesions, proliferations of stems, and abortion of pods. It is transmitted by aphids.

Root-knot nematode
[Meloidogyne spp. (Tylenchida: Heteroderidae)]
It has a wide host range and causes excessive branched and galled roots. It aids in Fusarium fungus entry into the roots.
Cutworm

*Agrotis ipsilon* (Lepidoptera: Noctuidae)]
Cutworm is polyphagous and spread around the globe. The larvae feed on leaves, stems, and roots of lentil. The older larvae cut the plant above the root zone. Weeds in and around the crop are major oviposition sites. The sporadic nature of cutworm populations makes preventive treatments futile. One way to control cutworm is to broadcast a poison bait prepared with wheat bran, cotton, or groundnut cake, and moistened with water. Parasitoids, *Bracon kitcheneri*, *Fileanta ruficanada*, and *Microgaster* spp., are common in India. Natural enemies recorded include parasitoids *Trichogramma* spp. (Hymenoptera: Trichogrammatidae), *Apanteles marginiventris*, *Microplitis* sp. (Hymenoptera: Braconidae), *Campoletis flavicincta*, *Hyposoter annulipes*, and *Ophion flavidus* (Hymenoptera: Ichneumonidae), and tachnid flies (Diptera: Tachinidae), and predators *Broscus punctatus* (Coleoptera: Carabidae) and *Liogryllus bimaculatus* (Orthoptera: Gryllidae). Entomopathogenic fungus (Metarhizium), nematode (*Steinernema carpocapsae*), and nuclear polyhedrosis viruses are effective in managing this pest.

Beet Armyworm

*Spodoptera exigua* (Lepidoptera: Noctuidae)]
This pest is widely distributed throughout the tropics and subtropics (Eastern Mediterranean countries and India). This is a polyphagous pest. The larvae of adult moths primarily feed at night and hide during the day and bury into the soil for pupation. The armyworm rarely causes economic damage in lentil. Pheromone traps are available for armyworms. Release of egg parasitoids, *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) and *Telenomus remus* (Hymenoptera: Platygastridae), for control of cutworms and other caterpillar pests.

Lima-bean pod borer

*Etiella zinckenella* (Lepidoptera: Pyralidae)]
The larvae feed on the soft green seeds within the pods and destroy the entire pod. Host plant resistance can successfully manage this pest. Short duration genotypes have been reported to have a higher larval population of *E. zinckenella*. The parasitoids *Bracon etiellae*, *Bracon pectoralis*, *Phanerotoma planifrons*, and *Pigeria piger* have been reported on larvae (Hymenoptera: Braconidae).

Bruchids

*Bruchus ervi*, *Bruchus lentis* (Coleoptera: Chrysomelidae)]
Bruchids are known storage grain pests; however, they do not reproduce in the storage. The adults feed on nectar and pollen and lay eggs on the young pods. Upon hatching, the larvae penetrate the pod and feed on developing seeds. Usually, single larva feed on the single seed. Larvae eat and create a thin circular exit hole. After pupation, the emerging adult leaves the pod through this exit hole. Adults remain in the seeds or hibernate in protected places such as residual crop. Hot air treatment and drying are major cultural management methods.
lentil IPM techniques

- Soil sanitation is necessary to manage soil-borne diseases and soil inhabiting insect pests.
- Organic soil amendments and mulching with oat or maize straw can be used.
- Sun-drying (exposing to 70-80o C) of seeds and application of bentonite dust and hydrated lime to control bruchids and seed-borne diseases.
- Crop rotation and a 2-3-year period without lentil production to reduce disease incidence.
- Changes in planting dates to avoid infection and infestation of some diseases and insect pests are recommended.
- Wide row spacing to reduce disease incidence.
- Weed management in the field to avoid alternate hosts for insect pests.
- Canopy management to manage microclimate to avoid diseases in lentil.
- Use of disease-free seeds.
- Entomopathogenic fungus, Beauveria bassiana, Metarhizium anisopilae, Paecilomyces lilacinus to manage stink bug and lygus bugs.
- Soil/seed application of Trichoderma harzianum, T. viridae, Bacillus subtilis, Pencillium spp., and Gliocladium virens can be used to manage collar rot.
- Soil inhabiting fungus Paecilomyces lilacinus used with neem cake, castor cake, mustard cake, and cotton cake controls nematode infestation in the field.
- Most of the diseases are seed-borne, hence treating seeds can be a good option. If Trichoderma is used, then use of gum arabic can increase its efficacy.
- Seed treatment with Rhizobium sp. for root-nodule development is useful.
- Foliar application of neem kernel extracts, neem oil, and pyrethrins are known to control the majority of insect pests without intense effect on the environment and grower’s health.
- Release of egg parasitoids, Trichogramma spp. (Hymenoptera: Trichogrammatidae) and Telenomus remus (Hymenoptera: Platygastridae), for control of cutworms and other caterpillar pests.
- Use resistant varieties.
Dimocarpus longan (Sapindaceae) is commonly known as the longan that produces edible fruit. This fruit is similar to the lychee (Litchi chinensis) and rambutan (Nephelium lappaceum), belonging to the same family. It is native to tropical Asia and is currently grown in China, Taiwan, Thailand, Malaysia, Myanmar, Indonesia, Cambodia, Laos, Vietnam, India, Bangladesh, Sri Lanka, and the Philippines in Asia; Mauritius, Kenya, and South Africa in Africa; Queensland in Australia; and Florida in the United States. Major production of longan occurs in China, Taiwan, Thailand, and Vietnam. In recent years, production of longan has increased due to improvements in agronomic practices and other aspects of crop management such as improved postharvest treatments and handling protocols and interest in exotic fruits in other parts of the world. Longan is an evergreen, subtropical tree with dense, dark green foliage, and can grow over 100 feet. Since it naturally grows in tropical conditions, it does not tolerate freezing temperatures. Short, dry, and frost-free winters are ideal for the development of flower panicles. Warm spring temperatures (ranging from 20 to 30°C) followed by high summer temperatures (ranging from 27 to 35°C) are best for fruit development. The peel (skin) of the fruit is tan or light brown, thin, leathery, and smoother than that of the lychee. The fruit is sweet, juicy, and succulent and apart from being eaten raw, it is also used in soups, snacks, and desserts. Longan trees are grown best in well-drained rich and sandy loam soils. Major abiotic stresses for this crop include salinity, flooding, and cold temperatures. Major biotic stresses include fungal diseases such as anthracnose, ceratocystis blight, and fruit rot, and insect pests such as fruit and shoot borers, mealybugs, scale insects, and mites. Longan fruit ripens in the hot season and therefore has a short shelf life at ambient temperatures. Other than high temperatures, pericarp browning and pathological decay is also a concern for fruit appearance.
**FUNGAL DISEASES**

**Fruit rot**  
*Phytophthora palmivora* (Pconosporales: Peronosporaceae)  
This is one of the most serious fungal diseases of longan. Young shoots, panicles, and fruits are most affected. It can survive in the soil and can spread through irrigation water, ants, and human activity. It causes necrosis of young shoots, flower drop, irregular lesions on fruits, and premature fruit drop. This disease is particularly harmful during cool weather after 2-3 days of rain. Proper sanitation, aeration, and reducing humidity by pruning decreases disease incidence.

**Sooty mold**  
*Meliola sp.* (Meliolales: Meliolaceae)  
Sooty mold fungus affects both fruit and leaves of longan that are attacked by sap-sucking mealybugs, Planococcus lilacinus, Pseudococcus sp., and Nipaecoccus sp. scale insects, longan wax scale, Ceroplastes ceriferus, and soft scale, Drepococcus chiton. These insects secrete honeydew that nourishes sooty mold. Although it does not cause direct damage, it reduces photosynthetic surface on leaves and infected fruits are downgraded. By controlling these insects, this fungus can be managed.

**Downy blossom blight**  
*Peronophythora litchi* (Pythiales: Pythiaceae)  
This fungal disease is common on litchi. On longan, it was first reported in 2000 in Taiwan. This disease causes droopy leaves and leaf blight. Water soaked lesions appear on young leaves, which turn into brown, round, or irregular lesions. Diseased leaves wither and collapse eventually. Humid conditions and continuous rain are favorable for this disease.

**Ceratocystis blight**  
*Ceratocystis fimbriata* (Microascales: Ceratocystidaceae)  
This fungal disease initially infects branches and later on causes wilting and eventually affects the whole tree. Abiotic factors such as water stress, extreme high or low temperatures, and micro-nutrient deficiencies increase the damage caused by this fungus. Mechanical damage caused by scolytid beetles, contaminated tools used for pruning, and ringing transmit this disease to healthy plants. Some varieties are more susceptible. Pruning and removal of infected plant parts help in managing this disease.

**Anthracnose**  
*Colletotrichum gloeosporioides* (Incertae sedis: Glomerellaceae)  
It is a foliar fungal disease and attacks both leaves and fruits. Symptoms on older leaves that appear as small spots in the margins coalesce to form large patches with brown borders. On young leaves and fruits dark brown lesions appear on the surface. Wet conditions increase its infection rates. Proper sanitation, aeration, and reducing humidity by pruning decreases disease incidence.

**NEMATODE**

**Sheathoid nematode**  
*Hemicriconemoides litchi* (Tylenchida: Criconematidae)  
The sheathoid nematodes are root-ectoparasitic. Recently, Hemicriconemoides litchi is found to be associated with the root system of longan in Taiwan. This nematode causes root malformation and nutrient deficiencies on agricultural fruit trees. However, above-ground evidence of damage may not become immediately obvious.
Fruit borer
[Conogethes punctiferalis (Lepidoptera: Crambidae)]
The adults are peach-yellow with scattered black spots. Older larval stages are light brown with dark brown heads and dark spots on the body. Damage is caused to the fruits when larvae bore into the fruits. The presence of frass on the fruit surface is an indication of the infestation. It pupates in soil and sometimes on fallen leaves. Monitoring by pheromone and/or light traps is recommended and pheromones are available. Bagging fruit clusters at 15 days after fruit set and destroying infested fruits helps in managing this pest. Application of neem formulations repels moths laying eggs on the fruits. In India augmentative release of Trichogramma sp. (Hymenoptera: Trichogrammatidae) and Chelonus blackburni (Hymenoptera: Braconidae) is used for control of this pest.

Fruit piercing moth
[Eudocma phalonia (Lepidoptera: Erebi-dae)]
These large noctuid moths are serious adult pests of ripe and ripening fruits. Both sexes of adults pierce ripening fruit, penetrate the skin and pulp of fruit with their modified mouthparts (proboscis) to withdraw juice and can cause crop losses of more than 50%. Microbial contamination from the proboscis of these moths results in rotting and premature fruit falling from the pierced fruits. Damaged fruits are unmarke-table and, if undetected and packed, pose a threat to sound fruit through pathogenic breakdown. Bagging of fruits effectively prevents damage by this moth. Egg parasites Trichogramma sp. (Hymenoptera: Trichogrammatidae), Telenomus sp. (Hy-menoptera: Platygastriidae), and Ooencyrtus sp. (Hymenoptera: Encyrtidae), and larval parasites Euplectrus spp. (Hyme-noptera: Eulophidae) and Winthemia sp. (Diptera: Tachinidae) have been reported to manage this pest.

Fruit and shoot borers
[Conopomorpha sinensis, Conopomorpha litchiella (Lepidoptera: Gracillaridae)]
Fruit borers are major pests wherever longan is grown. The adults are straw-colored moths with long filiform antennae, and fringed forewings, and mature larvae are brownish or green in color. Larvae of C. sinensis bore into the shoots or fruits, and generally, only one larva survives on each shoot or fruit. Pupation takes place under mature leaves. In absence of fruits, the larvae survive by feeding on young leaves or shoots. Larvae bore into fruits and feed on the seed. This damage to the fruits and seeds makes the fruits prone to infection by various microorganisms and causes fruit drop. Larvae of C. litchiella are pale green and mine in the leaf blades. The mature larva prefer to feed on the mid-rib and veins of young leaves causing distortion and twisting of young leaves. The density of fruit borers is high during the rainy season. Pruning of infested parts, bagging of fruits, and application of neem formulations are effective in the management of this pest. Pheromone and/or light traps could be used for monitoring the population. Larval parasitoids Tetrastichus sp., and Elasmus sp. (Hymenoptera: Eulophi-dae), Apanteles briaresae, Chelonus challi-ni, Colastes sp., Phanerotoma sp., Pholestesor sp. (Hymenoptera: Braconidae), and Goryphus sp. (Hymenoptera: Ichneumonidae), pupal parasitoids, Pha-nerotoma sp. and Apanteles sp. (Hymenop-tera: Braconidae) are known to occur on this pest.

Mite
[Eriophyes dimorcarpi (Acari: Eriophy-idae)]
This mite occurs in all growing areas of longan. The mite population increases in the dry season. It has been reported to be associated with longan witches’ broom syndrome. Mite feeding on meristems causes witches’ broom, which is a major problem in longan growing countries. This syndrome causes infected trees to have abnormally crowded panicles that lose their flowers prematurely, resulting in the characteristic ‘broom-like’ appearance of inflorescences. This disease stops young leaves from expanding and distorts mature leaves and leaves also show slight blistering, and necrosis and become crinkled. To manage this problem, infected shoots and inflorescences on longan trees should be removed and destroyed. Entomopathogenic fungus (Paecilomyces sp.), predatory mites [e.g., Amblyseius sp. (Acari: Phytosiiidae)] have been reported on this pest.

Lychee giant stink bug
[Tessaratomopsis papillosa (Hemiptera: Tessaratomidae)]
It is a polyphagous sap-sucking major pest of lychee and longan. Adults are golden brown and nymphs are elliptical (first instar), and rectangular (later instars) and orange-reddish. It has one generation per year and there are five nymphal instars. Nymphs and adults feed on tender plant parts like shoots, inflorescence, and fruits. Feeding causes necrosis of young twigs, withering of flowers, fruit rot, and fruit drop. Infestation is more prevalent in summer and low in rainy season. Heavy infestation can cause 80–90% yield loss. Entomopathogenic fungi, Beauveria bassiana, Paecilomyces sp., and Metarhizium sp. are effective in managing this pest. The egg parasitoids, Trissolcus

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**Eriophyes dimorcarpi, Kuang**
Thanhhoaensis (Hymenoptera: Aphelinidae), Eunotus sp. (Hymenoptera: Pteromalidae), Anicetus ceylonensis, Metaphycus sp. nr helvolus, Philosindia sp. nr longicornis (Hymenoptera: Encyrtidae), Cephaleta brunniventris (Hymenoptera: Pteromalidae) are reported to manage Drepanococcus chiton.

Psyllid
[Corneugenapsylla sinica (Hemiptera: Aphalaridae)]
This sap-sucking insect is found in Southeast Asia. This psyllid induces pit gall on young leaves of longan. The female adults are small with an average size of about 1.5 mm in length. Eggs are laid singly into the veins on the adaxial sides of the leaves. There are four nymph instars and they remain inside the galls. There are 3–5 generations per year. The psyllid is most abundant in summer. Feeding and gall induction causes economic damage due to direct feeding. Pruning and disposal of the severely affected shoots are recommended.

Mealybug
[Planococcus lilacinus (Hemiptera: Pseudococcidae)]
The mealybug Planococcus lilacinus is distributed throughout the tropics and suck the sap from host plants and excrete honeydew on fruits and leaves, which causes growth of sooty mold. In severe infestations, fruits are underdeveloped and drop off. The population usually increases during dry season. Pruning and destroying infected shoots can reduce mealybug populations. Ants play a major role in the dispersal of mealybugs. Baits are used for control of ants and help in reducing populations of mealybugs. Entomopathogenic fungus, Paecliozymes sp., and Metarhizium sp. are effective in controlling mealybug populations. Parasitoids, Tetrachemothidea indica (Hymenoptera: Encyrtidae), and Aprostocetus purpureus (Hymenoptera: Eulophidae), and the Triommatia coccidiva (Diptera: Cecidomyiidae), and Cacoelatus sp. (Diptera: Drosophilidae) are reported on P. lilacinus in Asia.

Scale insect
[Drepanococcus chiton (Hemiptera: Coccidae)]
Drepanococcus chiton is prevalent in south and southeast Asia. They suck sap from host plants and excrete honeydew on fruits and leaves, leading to the growth of sooty mold. In severe infestations, fruits are underdeveloped and drop off. The population usually increases during the dry season. Ants play a major role in the dispersal of scale insects. Baits are used for the control of ants and help in reducing populations of scale insects. Predators, Menochilus sexmaculatus, Coccinella transversalis, Cryptolaemus montrouzieri, Brumus sp., Scymnus coccivora, Chilocorus nigrara, M. sexmaculata, and Scymnus sp. (Coleoptera: Coccinellidae) and Suarius sp. (Neuroptera: Chrysopidae) are reported to manage scale insects. Parasitoids, Coccophagus thanhoaensis (Hymenoptera: Aphelinidae), Eunotus sp. (Hymenoptera: Pteromalidae), Anicetus ceylonensis, Metaphycus sp. nr helvolus, Philosindia sp. nr longicornis (Hymenoptera: Encyrtidae), Cephaleta brunniventris (Hymenoptera: Pteromalidae) are reported to manage Drepanococcus chiton.

Oriental fruit fly
[Bactrocera dorsalis (Diptera: Tephritidae)]
This is a polyphagous pest infesting more than 200 species of host plants. It lays pale yellow eggs under the skin of ripened or ripening fruits. The physical damage caused by ovipositional punctures as well as feeding damage by maggots leads to the rotting of fruits. Bagging fruits is an extremely effective strategy to manage this pest. A protein bait is developed in Vietnam (SOFRI-PROTEIN), which is made from beer waste and an insecticide, that attracts both male and female flies and kills them. Methyl eugenol traps also attract and kill male flies. These techniques in combination with orchard sanitation are effective in managing the fruit fly. Hot vapor or irradiation treatments are required before exporting the fruits to meet quarantine regulations of importing countries.

Indian wax scale
[Ceroplastes ceriferus (Hemiptera: Cocicidae)]

MINOR PESTS

Leaf miner
(Acrocercoeps cramerella) (Lepidoptera: Gracillariidae)

Mealybug
(Pseudococcus sp.) (Hemiptera: Pseudococcidae)

Spherical mealybug
(Nipaecoccus sp.) (Hemiptera: Pseudococcidae)

Grasshopper
(Oxya sp.) (Orthoptera: Acrididae)

Indian wax scale
(Ceroplastes ceriferus) (Hemiptera: Cocicidae)
• To increase fruit-bearing area, improve tree structure, and reduce wind damage, pruning should be done on young plants.

• To manage weeds, a 5–10 cm thick layer of mulch can suppress weed and grass growth. Wheat, rice straw, hay, and sorghum stubble can be used as mulching material.

• Fertilize the trees with compost inoculated with the antagonistic fungus, Trichoderma sp.

• To avoid mite infestation, flower induction from November to May should be avoided.

• After the final harvest, tree pruning should be done, and infected plant material should be safely disposed of by burying or burning.

• Prune and destroy shoots infected by witches’ broom syndrome.

• Set up light and/or pheromone traps to monitor fruit borer, litchi shoot borer, leafminer, and other pests.

• Trees can be netted to protect the fruit from birds, bats, and large insects.

• Set up methyl eugenol traps and protein bait for controlling fruit flies.

• Set up ant baits for managing ants, mealybugs, and scale insects.

• Apply Beauveria bassiana, Paecilomyces sp., or Metarhizium sp. for controlling stink bugs.

• Spray sulfur, neem oil, petroleum oil, or Paecilomyces sp. to control eriophyid mite.

• Bag the fruit cluster 15 days after the fruit set.

• Need-based pesticide application at the various stages of growth to manage diseases and insect pests. Use safe pesticides as the last option and do not use pesticides with the same mode of action continuously. Consult local extension officials for pesticide selection.

Longan bagging
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