

## Mitigating devastating diseases in vegetables

The diseases caused by *Phytophthora* spp. have emerged as major production constraints for sustainable vegetable production in India. Since 2008, severe outbreaks of *Phytophthora* diseases such as late blight on tomato (*P. infestans*), fruit rot on brinjal and cucurbits (*P. parasitica*), foliar blights and wilts in chili (*P. boehmeriae* and *P. capsici*) have been noticed. The migration of 13\_A2 genotype *P. infestans* from Europe is the cause of outbreaks of destructive late blight in India and this stresses the importance of bio-security in agricultural trade. The emergence of *P. boehmeriae* is responsible for severe leaf blight epidemics on hot pepper in south India, although it is not serious pathogen on any crop in any part of the world. These invasive and emerging *Phytophthora* species have epidemiological and management implications for production of vegetable crops in India.

VEGETABLES are important in human diet as they provide nutritional and health benefits. India is the largest producer of vegetables in world with an annual production of 133 million tonnes from 7.86 million ha, accounting 14.4% to the world production. Vegetable crops are largely cultivated by small and marginal farmers for their livelihood security. They are down by several diseases, causing in enormous losses. Their management on time is the pre-requisite approach in successful cultivation. Therefore all the methods for disease control are discussed.

### Blight on Capsicum

Capsicum is cultivated 0.94 million ha, with an annual production of 4.5 million tonnes. Although various diseases caused by fungi, bacteria and virus are reported in chilli, *Phytophthora* blight caused by *Phytophthora capsici* and *P. boehmeriae* is the most destructive disease. It is prevalent in all pepper-growing countries. *Phytophthora* affects all parts of pepper plant, causing a wide variety of symptoms. It causes pre- and post-emergence damping-off, root rot, stem blight, foliar blight, wilting and fruit rot. Symptoms can appear in 3 to 4 days after initial infection during warm and wet conditions. Symptoms

appear as small, water-soaked lesion on leaves and turn to a light tan colour. White fungal growth can be seen on blighted stems and leaves in wet periods.

Rapid blighting of leaves and shoots may occur. Infection on stem is common near soil but it can occur at any portion of stem. Stem lesions usually start as dark, water-soaked areas which later become brown to black and result in girdling, wilting and plant death. Infected roots turn black and rot. Fruit rot initiates as dark green, water soaked areas that become covered with a white to gray mold. Infected fruit dries, becomes shrunken and wrinkled, and remains attached to the stem.

### Disease Cycle

The *Phytophthora* is a soil-borne pathogen and survives as oospores in plant debris in soil for many years. Initial infection is caused by germination of oospores overwintering in soil or plant debris, followed by subsequent spread through zoospores dispersed into soil and aerial parts. The *P. capsici* can also spread through infected transplants, seed and through contaminated soil and equipment.

The *P. capsici* can spread by four distinct dispersal mechanisms such as: 1) movement of inoculum from root



Foliar blight in chilli

to root within and between rows either by root growth to inoculum, inoculum movement to roots or root-to-root contact, 2) spread of inoculum by surface water, 3) dispersal by rain or water splash from soil to leaves, stem and fruits and 4) aerial dispersal from sporulating lesions on leaves, stems and fruits. Unlike many other *Phytophthora* species that are favoured by 'cool and wet weather', *Phytophthora* blight is favoured by 'warm (optimum 24-33°C) and wet conditions'. *Phytophthora* blight begins to appear in June, 10-20 days after transplanting of seedlings into main field and continues till December due to prolonged period of wet conditions.

#### Disease Management

*Phytophthora* blight is a difficult disease to control, particularly once established in soil as oospores. Management strategies should combine cultural and chemical controls, along with other disease prevention measures. Plants should be planted in raised, crowned beds of more than 15-30 cm height to avoid water accumulation around the base of the plant. Planting pepper plants 4 cm above soil surface also reduces the disease severity. Irrigation at 15-21 days intervals reduces the disease incidence without affecting yield.

Drip irrigation close to stem can cause high incidence of disease whereas sub-surface irrigation encourages deep root growth in soil and minimizes the inoculum dispersal. By manipulating soil moisture levels, the disease incidence can be reduced. Water from



Fruit rot on chili



Stem and root rot on chili



Wilted plants of chili

infected fields should not be allowed to drain into disease-free fields. Although *P. capsici* is not a seed-borne pathogen, saving seed from a field where *Phytophthora* blight occurs should be avoided to restrict externally seed-borne infections. It is also highly useful to thoroughly clean all farm equipments that are used in an infested field before moving them to another field. Dispersal of soil-borne inoculum can be suppressed and final incidence of disease can be reduced by covering bare soil with straw mulches within and between rows.

Crop rotation with non-hosts, soil solarization and organic amendments can reduce the propagules in soil, thereby reducing the disease intensity. Cultivation of *Capsicum* should be avoided in a field that has been used for growing crops of bell pepper, cucurbits, tomato and brinjal earlier for a period of 3 years because *P. capsici* propagules persist in soils for repeated cultivation of susceptible crops. Intercropping with sesame, ginger, pea, onion, garlic, spinach and groundnut is very effective in suppressing *Phytophthora* blight in greenhouse conditions. Soil solarization with plastic mulches during summer months can reduce the soil inoculum.

Crop rotation with non-susceptible or non-host crops for at least 2 years is an excellent disease management strategy.

Removal and destruction of crop residue left from previous infected crops before replanting reduces the inoculum. Control volunteer crop

plants and susceptible weeds such as nightshade during crop rotations. The field should be scouted regularly for *Phytophthora* symptoms, especially after major rainfalls, and particularly in low areas of the field. When symptoms are localized in a small area of the field, the infected plants should be removed immediately. Cull all fruits with symptoms, and do not leave culls on the field.

Timing of fungicidal application seems to be more important for effective control of *Phytophthora* blight. Preventive sprays are more effective than curative sprays. Applying fungicides as soil drench around the stems are more effective than that of foliar sprays. Fungicidal sprays just before rainfall are more useful in reducing the disease incidence than sprays after rainfall. Fungicide seed-treatment and spray-application can prevent seedling death and reduce foliar blight and fruit rot. Seed treatment with either mefenoxam or metalaxyl can protect seedlings against *P. capsici* for up to 5 weeks after planting. Several fungicides such as copper hydroxide (2g/litre), chlorothalonil (2g/litre), mancozeb (2.5g/litre), mixtures of metalaxyl-mancozeb (2.5g/litre), cyamoxinil-mancozeb (2g/litre) and combination of dimethomorph-mancozeb/metiram/copper hydroxide (1:2g/litre), cymoxanil-famoxadone (1ml/litre), Fostyl-Al-propineb (2 : 2g), fenamidone-mancozeb(3g/litre) and iprovalicarb-propineb (4g/litre) are successfully for management of *Phytophthora* blight. Sequential sprays with different fungicides, starting from contact to mixtures of contact-systemic at weekly intervals, can provide effective protection against foliar blight and fruit rot caused by *P. capsici*. Combining seed-treatment with spray-applications can minimize crop losses by *Phytophthora*.

The planting of resistant cultivars greatly increases the fungicidal efficiency, thereby reducing number of sprays and risk of developing fungicidal resistance. The resistance of pepper to *P. capsici* was first identified in 1960 in certain genotypes. Pepper lines SCM334, CM334, NY07-8001, NY07-8006 and NY07-8007 have been reported to be tolerant to

*Phytophthora* blight in USA.

Later, pepper germplasm lines, CM331, CM334, PI 189550, PI201232, PI201234 and PI201238 have been identified as source of resistance to all the three pathotypes, 1, 2 and 3 prevalent in China, India, Indonesia and Thailand. A few resistant cultivars such as Adra, Emerald isle and Paladin were released for commercial cultivation in USA. A quantitative trait loci (QTL's), named as Phyto 5.2 QTL, located on chromosome 5 of pepper plants linked to resistance in many resistant germplasm in *C. annuum* and *C. chinense* have been identified, which can be used in future breeding programmes.

Antagonistic microorganisms such as *Streptomyces violaceoniger*, *Pseudomonas cepacia*, *Pseudomonas aeruginosa* and *Trichoderma harzianum* were highly effective against *Phytophthora* blight on chilli under laboratory and greenhouse conditions. Soil drenches and dipping of seedlings with biocontrol agents were more effective than seed treatments. The concentrations of  $10^5$  and  $10^7$  CFU/g soil for *Trichoderma harzianum* and *Pseudomonas cepacia* respectively required for disease suppression. Extensive field trials indicated that efficacy of biological control varied from place to place and year to year and their performance is dependent on extent of colonization in soil and availability of required concentrations.



Late blight on tomato



Late blight symptoms on stem of tomato

### Late Blight of Tomato

Tomato is one of the most popular vegetables grown all over the world for its fleshy fruits. Late blight is one of the most devastating diseases of potato and tomato worldwide. Prior to 2008, late blight was not considered a serious threat to tomato in India even though the disease was known on potato since 1903. However in 2006, 2007 and 2008, severe late blight epidemics have occurred both on potato and tomato in southern states of India and migrating to northern states like Uttar Pradesh.

The infection occurs on all above ground parts of the plant, viz. leaves, stems and fruits at all stages of plant growth. Late blight appears on tomato leaves as pale green, water-soaked spots, often beginning at leaf tips or edges. The circular or irregular leaf lesions are



Leathery symptoms on tomato due to late blight



Buck eye rot on tomato

often surrounded by a pale yellowish-green border that merges with healthy tissue. Lesions enlarge rapidly and turn dark brown to purplish-black.

During periods of high humidity and leaf wetness, a cottony, white moldy growth is usually visible on lower leaf surfaces at the edges of lesions. In dry weather, infected leaf tissues quickly dry up and the white mold growth disappears. Infected areas on stems appear brown to black and entire stem may be killed in a short time when moist weather persists.

*Phytophthora infestans* produces gray-green, water-soaked spots on fruits, which enlarge, coalesce, and darken, resulting in large, firm, brown, leathery-appearing lesions. While *Phytophthora parasitica* causes symptoms like “buck eye” rot on fruits. The symptoms of buck eye rot first appear as a green to brown water-soaked lesions near the blossom end of the fruit, especially if it is in contact with moist soil. Later, the spot rapidly expands and covers the fruit surface with definite zonations or dark concentric rings. If conditions remain moist, abundant white mould develop on lesions, and secondary soft-rot bacteria may follow, resulting in a slimy wet rot of the entire fruit.

Management of late blight on tomato requires a multifaceted approach. The disease cannot be eliminated as it is soil borne and it can be managed by using integrated approaches to crop production and protection. Cultural methods cannot prevent disease

during seasons with wet, cool weather. However, following practices help to certain extent to reduce the disease severity.

- Plant only healthy tomato transplants. Check to make sure plants are free of dark lesions on leaves or stems.

- Planting at recommended space (100cm × 60cm), raising the crop in raised beds, removing lower leaves, infected fruits and staking of plants to frames to avoid contact of fruits with soil for good air circulation.

- Reduce inoculum of the fungus by eliminating potato and tomato cull piles and plant debris in and around the planting area.

- Avoid wetting foliage when irrigating, especially in late afternoon and evening.

- When the crop is raised during July-December, scout the tomato crop for symptoms of late blight once in two days. Check more often during periods of wet weather. If any late blight symptoms are noticed in the field, spray the fungicides immediately.

- Higher dose of nitrogen favour the disease while potassium has no impact.

- Commercial cultivars do not have sufficient

resistance to *P. infestans* to reduce the disease development. The cultural practices may not be effective once disease starts. At present, chemical control is the only option that can prevent crop destruction if sprays were taken before disease appears.

The pathogen generally survives on infected plant debris. Primary infections initiate from debris in the soil. Secondary infections start from wind-or splash- born sporangia from primary infections on tomato plant. Sporangia or zoospores can penetrate living cells within 2h when the conditions are favourable. After penetration, *P. infestans* establishes near bio-trophic relationship and lesions visible within 3-5 days under optimal conditions (18-22°C) although disease can occur over a range of temperatures from 5 to 30°C. After one or two days of visible symptoms appearance, the pathogen produces sporangia under moderate temperatures (10-25°C) and wet conditions (leaf wetness or RH > 95%). Sporangia are released during the day when RH is lower and can be carried in air currents or rain splash dispersed. Sporangia can survive for many hours in atmosphere on cloudy days and are killed within an hour when higher solar radiation prevails. On cloudy days, the sporangia can be carried to hundreds of meters or kilometers. When the conditions are favourable, more than 1,00,000 sporangia can be produced in a single lesion. Historically, the disease has been associated with ‘cool wet weather’. Cool nights and warm days with moist weather, which prevail during July-December are the best conditions for development of the disease.



Integrated management of late blight of tomato

- Spray at regular intervals. Begin chemical control programmes before symptoms appear. First application at 2-4 true leaf stage, then at one- or two-week intervals as required to control disease. In high disease situations, use shorter spray intervals.
- Use of a good protectant fungicide programme is necessary to fully protect any crop of tomato, which means that they must be on the foliage before spores land on leaves that are wet from rain, irrigation, fog, or dew. Therefore, continuous fungicide coverage is necessary to protect plants from infection.
- Protectant fungicide like Bordeaux mixture as prophylactic foliar spray is highly effective in control of late blight but it is toxic to the foliage if preparation is not good. Copper hydroxide (2g/litre) chlorothalonil (2g/litre) and mancozeb (2.5 g/litre) fungicides are the standard protectants used for control. They are usually applied

every 7-10 days for best protection.

- The pre-packed fungicide mixtures like, metalaxyl-mancozeb (2.5g/litre), cyamoxinil-ancozeb (2g/litre) and combination of dimethomorph-mancozeb/metiram (1:2.5g/litre), cymoxanil-famoxadone (1ml/litre), Fostyl-Al-propineb (2:2g), fenamidone-mancozeb(3g/litre) and iprovalicarb-propineb (4g/litre) are highly effective for

management of late blight development. Under heavy disease situations, spray at 5-7 days intervals is essential. However, metalaxyl-mancozeb combination should be used with care as fungus develops tolerance to metalaxyl.

- The cultivated tomato lack resistance to late blight. However, wild tomato (*L. pennellii*, *L.pimpinellifolium* and *L.hirustum*) are resistant. The tomato breeding lines, CULBPT-A46 and CULBPT-A48, with commercially acceptable horticultural traits, resistant to multiple clonal lineages of *P.infestans* were released during 2006 in USA. In Tanzania, two of the best performing lines, LBR19-2 and LBR44-2, resistance to late blight,

#### Blight on brinjal

Phytophthora blight on brinjal is caused by *Phytophthora capsici* and *Phytophthora parasitica*. *Phytophthora* can move in water, any plant parts that contact the soil have a greater chance of becoming infected. *Phytophthora* sp may survive in and on seed and host plant debris in the soil by means of oospores. The oospores germinate and produce sporangia and release zoospores. Zoospores are motile and swim to invade host tissue. Plentiful surface moisture is required for this activity. The sporangia are spread by wind and water through the air and are carried with water movement in soil. *P. capsici* is also move as hyphae along with infected transplants and through contaminated soil and equipment. Since water is integral to the dispersal and infection of *P. capsici*, maximum disease occurs during wet weather and in low or waterlogged parts of fields. Excessive rainfall, coupled with standing water creates ideal conditions for epidemics. Growth of this pathogen can occur between 7-37°C, but temperatures between 27-32°C are optimal for producing zoospores and the infection process. Under ideal conditions, the disease can progress very rapidly and symptoms can occur 3-4 days after infection.

were released as new varieties under trade names 'Meru' and 'Kiboko' in 2007 and 2008, respectively

- An integrated approach consisting of spraying of protectant chemicals like, Bordeaux mixture, copper hydroxide or mancozeb or chlorothalonil well before the symptoms appear, along with staking and removal of foliage and fruits up to 30 cm, weeding, mulching with polythene sheet followed by spraying of pre-packed mixtures of systemic and contact fungicides like dimethomorph-mancozeb/metiram, cymoxanil-famoxadone, or fenamidone-mancozeb and iprovalicarb-propineb, at 7-10 days intervals depending on weather conditions, is most economical.



Fruit rot on brinjal

### Fruit Rot on Brinjal

Brinjal is one of the most common vegetables grown throughout the country. *Phytophthora* can affect its roots, crowns and fruits, but symptoms on fruits are most frequently seen. The roots and crowns turn brown and rot, causing plant wilting. Although the entire plant may be susceptible, fruit rot is the primary symptom. It begins as a round, dark brown area on any part of the fruit at any stage of maturity. The initial lesion is surrounded by a rapidly expanding light tan region. White to gray fungal growth that look like "powdered sugar" may appear during wet, humid periods, starting on the oldest part of the fruit lesion. These spots expand rapidly and can cover mature fruit in 3-4 days.

The fungus penetrates deeply within the fruit, resulting in a brown discoloration of the flesh. Diseased fruit drop prematurely. *Phytophthora* fruit rot lacks the concentric patterns and dark fruiting structures present with *Phomopsis* rot. The *Phytophthora* also cause damping off in the

*Phytophthora* blight is caused by the *Phytophthora capsici*. The disease is usually associated with heavy rainfall, excessive-irrigation, or poorly drained soil. Frequent irrigation increases the incidence of the disease. *Phytophthora* survives on seed and host plant debris in the soil. *Phytophthora* spreads through transplants and soil and equipment. Since water is integral to the dispersal and infection, maximum disease occurs during wet weather and in low, waterlogged parts of fields. Growth of this pathogen can occur between 7-37°C, but temperatures between 27-32°C are optimal for producing zoospores and the infection process. Under ideal conditions, the disease can progress very rapidly and symptoms can occur 3-4 days after infection. Various disease control practices can be integrated to manage *Phytophthora* blight, including: exclusion, cultural practices, and chemical control. The most effective method of control for *Phytophthora* blight is to prevent *P. capsici* from moving into a non-infected field. *Phytophthora capsici* spreads by soil, water, and/or plant material. All farm equipment that is used in an infected field should be thoroughly cleaned before moving it to another field. Water sources (ponds or reservoirs) should be avoided that receive run-off water from an infected field. Water sources can be tested for the presence of the pathogen by baiting techniques. *Phytophthora capsici* is not considered a seed-borne pathogen; however, saving seed from a field where *Phytophthora* blight occurred should be avoided.

seedlings. The fungus attack usually starts on the germinating seed, spreading to the hypocotyl, basal stem, and developing tap root. The affected seedlings are pale green, and a brownish lesion is found at the basal portion of the stem that girdles the stem. The affected tissue rots and the seedling collapses.

Taking early preventive management measures against *Phytophthora* is the best way to avoid losses due to *Phytophthora* blight. Planting should be done in well

drained, tiled fields. Beds should be raised and drip irrigation should be used. Warm, wet weather is most conducive to *Phytophthora*, so it is important to use a drip irrigation system and be vigilant when weather favors disease development. Surface water for irrigation should be avoided. Crop rotation should be practiced. Diseased plants should be removed. Dumping of diseased culls in production field should not be dumped.

The disease is soil-borne. The disease may be controlled by soil sterilization and seed treatment with fungicides or hot water. Proper sanitation measures can keep spores from overwintering and infecting the next crop. At the end of the growing season, all plant refuse should be removed and discarded. Any infected fruit should be removed during the growing season or at the end of the season. Growing brinjal on plastic



Crown rot on bottle gourd

mulch greatly reduces the chance of spores splashing from the soil to the fruit. Chemical control of *Phytophthora* is difficult due to the rapid rate of development of the disease, especially under optimal weather conditions. *Phosphorous* acid, copper hydroxide, mancozeb and chlorothalonil can be used.

#### Diseases on Cucurbits

In India, a number of major and minor cucurbits are cultivated, which share about 5.6 % of the total vegetable production. They are consumed in various forms, *i.e.* salad (cucumber, gherkins, long melon), sweet (ash gourd, pointed gourd), pickles (gherkins), and deserts (melons). *Phytophthora* causes seedling damping-off, root and crown rot, leaf spots, stem lesions, foliar blight, and fruit rot. Crown rot causes the entire plant to collapse and die in a short period of time.

Leaf spots are dark brown, one to several centimeters inches in diameter. Vines can be affected at any part. The lesions are dark brown, water-soaked, and girdle the stem, causing the stem to collapse and die. *Phytophthora* foliar blight and fruit rot are very common in cucurbit crops. Fruit rot generally starts on the side of the fruit that is in contact with the ground.

The depression in the fruit surrounding the stem attachment serves as a reservoir of moisture providing favorable conditions for infection. Infection of a fruit may also start at the site where an infected leaf or infected vine comes in contact with the fruit. Fruit rot typically appears as a water-soaked lesion, expands, and becomes covered with fluffy white mold.

It causes pre- and post-emergence damping-off in processing pumpkin plants in wet and warm (20-30°C) soil conditions. In seedlings, a watery rot develops in the hypocotyls at or near the soil line, resulting in plant death. Post-emergence seedling death is preceded by plant wilting. Mature plants show symptoms of crown rot. Initial symptoms include a sudden, permanent wilt of infected plants without a change in color. The wilt of leaves progresses from the base to the extremities of the vines. Often plants die within a few days of the first symptoms or after soil are saturated by excessive rain or irrigation.



Watery rot on hypocotyls of ridge gourd

The stem near the soil line turns light to dark brown and becomes soft and water-soaked. Infected stems collapse and die. Tap and lateral roots of infected processing pumpkin plants usually do not exhibit any symptoms. Following death of the foliage, roots may give rise to new vines if environmental conditions become less conducive for development of disease. *Phytophthora* damping-off may result in partial to total loss of the crop.

The *P. capsici* can survive in soil for several years, fields without a history of *Phytophthora* blight should be selected for planting. Although no cropping rotation period has been established for effective management of *Phytophthora* blight of cucurbits, it is recommended to select only fields that have not had a history of cucurbits, brinjal, peppers, and/or tomatoes for at least 3 years.

Fields should be selected that are well isolated from fields infested with *P. capsici*. High soil moisture favours the development of *Phytophthora* blight, thus well-drained fields should be selected and excessive irrigation should be avoided. Planting cucurbit crops in areas of the field that have poor drainage should be avoided. The field should be scouted regularly for *Phytophthora* symptoms, especially after major rainfalls, and particularly in low areas of the field. When symptoms are localized in a small area of the field, the infected plants should be plowed into the soil. Plants should be sprayed with effective fungicides at the first sign of the disease. Healthy fruits should be removed from the infected area as soon as possible, and they should be checked for disease development routinely. Growing cover crops and/or mulching can also be used to manage the dispersal of the pathogen.

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