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Review Article

A review on major and minor Diseases affecting Pipper nigrum L.: The king of spices

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A R T I C L E I N F O

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A B S T R A C T

Pepper (Piper nigrum. Linn) (Piperaceae) is considered as the "King of spices", a widely used spice that has been extensively explored for its biological properties and its bioactive Phyto compounds. However, crop loss through the attack of pests and pathogens is a big challenge for producers and scientists. Eradication of diseases on infected farms is impossible. Therefore, it seems a need to possess enough knowledge regarding different pests and pathogens. The identification of pest and pathogen, its occurrence, transmission, and symptoms observed in plants need to be studied and analyzed. So, for these purposes, the review has highlighted the major and minor diseases occurring in pepper and resulting in yield loss and crop damage.

K E Y W O R D S

Piper nigrum | Foot rot disease | Phytophthora capsici | Anthracnose | Colletotrichum piperis | Leaf gall thrips | Red rot | Pollu beetle | Longitarsus nigripennis| Elachertus.

C I T A T I O N

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Introduction

Spices form an essential part of human consumption since the rise of human race. As they have been continuously used from years to increase the quality of nutrition and also recognized for their preservative characteristics and medicinal properties (Catillo *et al*., 2020). Piper species belongs to the Piperaceae family which is considered to be among the most ancient of flowering plants growing in tropical regions, comprising of 13 genera (Takooree *et al*., 2019). This diversified genus Piper includes 4,166 scientific plant names of species rank; of these 1,457 are accepted species names, 1,376 synonyms, and 1,333 unassessed (Salehi *et al*., 2019).

Piper nigrum L., also known as pepper, is considered to be the "king of spices" because of its huge importance and trade share in the global market. The name "pepper" originates from the Sanskrit word pippali, which means berry (Takooree *et al*., 2019). Piper nigrum is a perennial woody aromatic climber that may grow to a height of 50–60 cm (Choi *et al*. 2020). According to Andriana *et al*., (2019) P. nigrum, is native in Kerala in Southwestern India and widely distributed in tropical regions, including Indonesia. Its fruits are usually dried and used for spices and seasonings. This plant is used as a folk medicine to treat gastrointestinal disorder, rheumatic, flu, colds, muscular aches, and fever diseases. Biological activities of P. nigrum have been known as insecticidal, larvicidal, antioxidant, and antimicrobial activities. According to Salehi *et al*., (2019) geographically, P. nigrum is mostly cultivated in hot and moist conditions. The primary areas of the black pepper cultivation are in the Western Ghats of the South Indian Peninsula, subsequently was introduced to other countries in South and Southeast Asia. Piper nigrum is mainly used as a culinary item in a wide variety of dishes. In Western cuisine, black pepper is principally used as a seasoning ingredient to enhance food flavor as well as in food preservation. White and black peppers are different in their time of harvest and processing techniques. White pepper is obtained by removing the pulp from ripe fruit, while the black pepper is produced by drying unripe fruit until a wrinkled formed; therefore, black pepper contains the pulp. Both white and black pepper has a wide range of applications, like spices, preservatives, insecticides, and also in herbal medicine (Quijia and Chorilli, 2020). Ground white pepper is used in Thai and Chinese cuisine, in the preparation of salads, cream sauces, and light-colored sauces. Apart from its culinary uses, P. nigrum has immense importance in folk medicine in several countries. The phytochemistry analysis of this plant is widely studied by the scientific community, and a wealth of literature has emerged.

Crop loss

Black pepper cultivation in India has been under threat due to severe infestation and infection. According to Research and Market (2020), on a global scale, crop production has been estimated to be around 725K tonnes in 2020. About 25-35% vine death has been reported in Kerala. The disease has been spreading at an alarming rate all over the black pepper growing tracts during the last 15 years. Pathogens can attack all parts of the black pepper plant at any stage of crop growth (Sarma *et al*., 1994). According to Anith *et al*., (2003) none of the cultivated or wild varieties of black pepper show resistance to the disease. Plants when faced with unfavorable environmental conditions and parasitic microorganisms can cause disease. The plant disease-causing agents are mainly called pathogenic microorganisms (*i.e.*, viruses, bacteria, fungi, protozoa, nematodes) unfavorable environmental conditions (such as lack or excess of nutrients moisture and light) or even the presence of toxic chemicals in air or soil. Diseases in plants effect major production and economic losses as well as the reduction in both the quality and quantity of agricultural products. Nowadays, plant disease

detection has received increasing attention in monitoring a large field of crops. Farmers experience great difficulties in switching from one disease control policy to another. The naked eye observation of experts is the traditional approach adopted in practice for the detection and identification of plant disease. A symptom of plant disease is a visible effect of disease on the plant. Symptoms include a detectable change in color, shape, or function of the plant as it responds to the pathogen. Leaf wilting is a typical symptom of verticillium wilt, caused by the fungal plant pathogens Verticillium albo-atrum and V. dahlia. Common bacterial blight symptoms include brown, necrotic lesions surrounded by a bright yellow halo at the leaf margin or interior of the leaf on bean plants (Nyvall, 2013). We are not actually seeing the disease pathogen, but rather a symptom that is being caused by the pathogen. A sign of plant disease is physical evidence of the pathogen. According to Anandaraj *et al*., (1991) bacterial canker of stone fruits causes gummosis, bacterial exudates emerging from the cankers. The thick, liquid exudate is primarily composed of bacteria and is a sign of the disease, although the canker itself is composed of plant tissue and is a symptom.

Pests and Pathogens: Limiting factors

Crop pathogens and pests reduce the yield and quality of agricultural production. They cause substantial economic losses and reduce food security at household, national and global levels. According to the studies the pepper plant faces serious leaf diseases. Plant diseases are divided into parasitic and non-parasitic microorganisms. The major plant pathogens are fungi, bacteria, viruses, and nematodes. Fungi are the common cause of plant diseases. According to Thornton and Wills (2015), more than 10,000 species of fungi are detected to cause diseases in plants. 50 species cause diseases in humans and many cause diseases in animals. Most plant diseases around 85% are caused by fungal or fungal-like organisms. The effect of fungi on plants can be very terrible. It can destroy the cellular structure, formulate the physiological functions unstable and the rate of metabolic pathways are damaged by many factors that influence the sequences from the germ tube emergence to attachment, adhesion, aspersorium development, and the plant surfaces for the penetration to the plant (Azhar, 2013). Some fungi degrade the cell wall to enter the plant, other than that forming specialized structures i.e., appressoria to penetrate and enter the epidermis while others enter the host through natural opening even by thigmotropism or chemotropism (Lauren and Nicholas, 1996).

Another most common pathogens are algae. Algae are not normally considered as common pathogens. Plants so far reported to be infected by the endophytic alga Cephaleuros in India are less common. Infection occurs as dark-reddish or brown-greenish spots on the dorsal surface of leaves. The alga undergoes considerable variation under different conditions on the same host. Severe attacks of the alga occurred during the rainy season. The morphological variation of the alga is different. The genus Cephaleuros is a well-known parasitic or endophytic alga which at times causes serious damage to cultivated crops. A disease caused by this alga on tea plants is known as "Red Rust of Tea", and is a serious problem in plantations. This disease is more prevalent in north-eastern India, identified vires¬cens as the causative agent, and said that Cephaleuros began to attract attention since 1880 as the cause of "white blight". The algae have a wide distribution in tropical and subtropical regions. In India, the occurrence of the alga as Mycoidea parasitic on tea plantations was observed from Assam and in 1897 the same algae as virescens Kunze. Since then many workers have reported its occurrence on various hosts. According to Freire, (1982) virescens as a causative agent of black fruit disease of pepper vines in Sarawak and listed all known plants infected by the alga in tropical plants of economic value.

Among the various pests which attack pepper, Liothrips karnyi is important as it deforms and damages the leaves by making marginal galls. Both the adults and larvae feed on the leaves and cause marginal folded galls. So far no chalcidoid parasitoids are known to attack this pest. According to Narendran and Bindu (2009), Elachertus piperis a new species of eulophid parasitoid (subfamily: Eulophinae) which has emerged from this thrip galls. It is quite likely that this parasitoid is a natural enemy of L.karnyi and may prove to be a useful biological control agent.

Diseases

According to M. Anadrai and Y. R Sharma on "Diseases of black pepper" it was found that although 17 diseases are recorded in black pepper (Piper nigrum L.). In the past four years, black pepper plants have been affected by new diseases other than root rot and stem blight (Nectria haematococca f. sp. piperis). The 4 major diseases are Phytophthora foot rot, blackberry disease, wrinkled leaf disease caused by a virus and root-knot disease caused by Meloidogyne incognita and M. Javanica.

Foot rot disease

Foot rot disease is caused by Phytophthora capsici which is a soil-borne fungus. Phytophthora foot root causes high mortality of cuttings and severe economic losses. It infects all parts of the vine. The severity of the disease depends upon the plant part affected and the extent of damage and all the parts of the plant are susceptible to the fungus (Anadraj *et al*., 1991) The disease has two important phases i.e., Aerial phase and soil phase.

Pathogen: Phytophthora capsici (P. capsici) is one of the most important vegetable pathogens worldwide (Fernandez *et al*., 2004). It is an oomycete soil-borne plant pathogen that causes root, fruit, and foliar disease on a variety of vegetables. Plants that are infected by this pathogen will die within 2 - 3 weeks in rain and adjacent plants will be infected within one or two months. The quick death of Piper nigrum can be presented that phytophthora spores develop into the roots and stems, especially collar causing foot rot. Rotting of collar destroys phloem and xylem, preventing the transfer of water and nutrient from the roots to aerial parts of the plant. Therefore, the plant died intermediately with symptoms of sudden leaf wilting and dropping.

Reproduction: Also, the reproduction process of the pathogen in several types, both sexual and asexual means. Meanwhile, mycelia produce three asexual spores including sporangia, zoospore, and chlamydospore. Zoospores are the major propagules of infection (Pérez-Jiménez, 2008). According to Hausbeck and Lamour (2004), each oospore that produces a male and female gametangium, so-called antheridium, and oogonium respectively serve as the overwintering inoculum of the pathogen. Moreover, under a good condition of free moisture on plant surface or saturated soil, sporangia release motile and biflagellate zoospores. Each sporangium produces 20 to 40 motile zoospores under free water conditions (Mchau and Coffey, 1995). Additionally, sporangia and zoospores are secondary inocula and they can be reproduced repeatedly during the growing season, causing a rapid escalation of disease (Nam, 2012). The life cycle of the pathogen is one of the elements that contribute to maintaining and developing pathogens. Temperature (20˚C - 28˚C) and moisture (>80%) are optimal for both chlamydospores and oospores live over 6 years in the soil; 2 - 3 rainy seasons in dead plant materials (Nambiar and Sarma, 1982). More importantly, inoculum can survive in the soil up to 19 months without host plants (Kueh, 1990).

Symptoms: The first symptoms of the disease are very hard and often undetected by farmers and technicians. They detected disease when the upper part of pepper vine shows performance as leaf yellowing, wilting, and dropping (Ton *et al*., 2011). Once these symptoms are observed, the infection is already at its severe stage with most of the root rotted and the underground stem showing

a brownish-black lesion. Different phases of symptoms are aerial and soil phase:

Aerial phase: Appearance of dark brown lesions with fimbricate margins of leaves and rotting of aerial portions of stems and spikes resulting in varying degrees of defoliation and spike shedding causing the reduction in spike size.

Soil phase: According to Anandraj *et al*., 1994 initially the infection goes unnoticed but later greater root loss and foliar yellowing are observed. The infection further spreads from feeder roots to thicker roots ultimately leading to the death of the vine. Although quick wilt is also called sudden death occurs when an infection is confined to collar or foot independently and feeder rots lead to a slow decline. According to Yellareddygari *et al*., (2011) bacterial spot is caused by the bacterium Xanthomonas campestris. The pathogen invades pepper through wounded roots inflicted by nematodes (Meloidogyne incognita and M. javanica) are during the emergence of new roots. It colonizes the vascular bundles causing necrosis and preventing water and nutrients uptake. The vascular necrosis, unilateral initially, extents to the leaf veins of apical twigs resulting in quick wilt and death of plants. Externally, diseased plants show yellowing, shedding of leaves and internodes, and lack of rootlets. The internodes show triangular and necrotic lesions around the nodes of the main branch, which result in unilateral necrosis of the internode turn them half green half necrotic. When several roots are infected, the plant collapses getting the foliage adhered to the branches. If branches are cut, necrotic vessels of phloem can be seen immediately below epidermis.

Anthracnose

According to Kurien *et al*., (2000) anthracnose is also called blackberry disease and is caused by Colletotrichum capsici, C. piperis, and C. gloeosporioides. Black pepper (Piper nigrum L.) is affected by various diseases in Kerala among which anthracnose caused by Colletotrichum gloeosporioides (Penz) Penz & Sac. is gaining importance in recent years. The fungus causes damage to the plant both in the nursery and field. On older vines in the field, leaves, spikes, and berries are affected. Infection on spikes results in spike shedding, whereas, infection on immature berries leads to the formation of brownish splits on the berries. Spike shedding is more severe at high altitudes. The disease is seen throughout the crop season in plantations and maximum damage is caused from August to September and ranges from 28% to 34%. The damage to the berries due to C. gloeosporioides has also been reported to result in a 100% yield loss (Chethana *et al*., 2000).

Pathogen: According to Shenoy *et al*., (2007) Colletotrichum capsici is a fungal plant pathogen with a wide host range, including 121 host-genera in 45 plant families. The sexual ascomycete form is rarely found in nature. Conidiophores are 3-45 × 2-6 µm, hyaline, cylindrical, unicellular, or septate. Conidiogenous cells are 6-10 µm × 2.5-4 µm wide, hyaline, ellipsoidal to subglobose, conidia are 7-14 µm × 2.5-3.5 µm, one-celled, gluttulate, hyaline, fusiform with both ends pointed. Colletotrichum capsici is an air-borne, seed-borne, and also soil-borne pathogen. It can survive in moist soil and plant debris for several years. The fungus can spread by rain splash and irrigation water. It can also spread by infected soil, farm tools, and shoes.

Symptoms: According to Than *et al*., (2007) anthracnose can cause extensive pre- and post-harvest damage, as well as pre-harvest symptoms on leaves and stems. Often, symptoms of the post-harvest disease do not develop until the fruit is ripe. Typical symptoms are circular or angular sunken lesions on fruits, with concentric rings of acervuli. Orange conidial masses are often produced in acervuli creating a surface that is wet and slimy. Lesions may coalesce under severe disease pressure. The fungus can be carried by seeds intraembryonally. Enzymes produced by C. capsici can disrupt seed tissues. Conidial masses

generated from the acervuli can serve as a primary inoculum source. The fungus can spread from the seed to the placenta of the fruit, then penetrate the developing ovules or young seed. The infection of seeds can also occur directly from the mother plant. Conidia can remain dormant on the surface of the testa until seed germination (Lewis *et al*., 2004).

Leaf gall thrips

Leaf gall Thrips (Liothrips karnyi Bagn.) damage has a huge effect on the demand for pepper planting materials under nursery conditions. Leaf gall thrips are caused by Liothrips karnyi which is important as it deforms and damages the leaves by making marginal galls. Both the adults and larvae feed on the leaves and cause marginal folded galls. So far no chalcidoid parasitoids are known to attack this pest.

Pathogen: Liothrips Karnyi belongs to insect Thrips which live in colonies within tubular marginal galls induced by them. The thrips are <3 mm in length and black. Eggs are laid within the marginal galls on the leaf surface singly. Emerging thrips pass through first and second nymphal, prepupal and pupal instars and become adults in 13-18 days. All stages of thrips are seen in the marginal galls.

Symptoms: Margins of infested leaves are folded and thrips feed on inside these marginal galls. Eggs and other immature stages can be seen inside the galls. Severe damage results in yellowing and shedding of leaves. Downward and inward curling of leaves resulted in the formation of marginal leaf galls. Later the infected leaves become crinkled and malformed. In severe cases of attack, the whole plant may become stunted, affecting adversely the formation of spikes.

Red rot or blackberry disease

Cephaleuros virescens are the causative agent of red rot or blackberry disease. Species are filamentous green algae and parasites of higher plants. The disease is called algal leaf spot, algal fruit spot, and green scarf; Cephaleuros infections on tea and coffee plants have been called “red rust.” These are aerophilic, filamentous green algae but still require a film of water to complete their life cycles.

Pathogen: The genus Cephaleuros is a member of the Trentepohliales and a unique order, Chlorophyta, which contains the photosynthetic organisms known as green algae. Cephaleuros species consist of branched filaments that comprise a thallus in the form of irregular discs. The thallus grows below the cuticle or sometimes below the epidermis of the host plant. This pigmented thallus (orange to red-brown) consists of a prostrate portion that is branched irregularly with irregular cells and an erect portion of unbranched hairs, with cylindrical cells, sterile or fertile, protruding through the cuticle. Haustorial cells are sometimes present inside the plant host’s tissue.

Reproduction: Sporangiophores bear one or more head cells subtending sporangiate-laterals. Gametangia are terminal or intercalary on the prostrate cell filaments. Cephlaeuros species are capable of both asexual and sexual reproduction. Through sexual reproduction, the resulting zygote produces a dwarf sporophyte. The life history consists of an alternation of heteromorphic generations, with the sporophyte reduced to a dwarf plant. The asexual stage is probably much more important to the typical infection and disease processes. These pathogens are dispersed by wind and splashing water.

Symptoms: Symptoms and crop damage can vary greatly depending on the combination of Cephaleuros species, hosts, and environments. C. virescens is a subcuticular parasite, while C. parasiticus is an intercellular parasite. Spots caused by C. parasiticus on guava leaves are a top-down, intercellular, full-thickness necrosis, destroying both upper and lower epidermal cell layers and all intervening tissues. Then, a bright but relatively sparse orange algal bloom bursts forth from the undersides of leaf lesions, rather

than from the upper side of leaves as is usually the case with C. virescens, the more commonly occurring species in the genus. The distinctive and much more common spots caused by C. virescens on many hosts in Hawaii appear on the upper leaf surface as raised yet flattened, textured, burnt-orange to brown or rust-colored, circular areas up to about 2 cm in diameter, having indistinct, filamentous margins and fuzzy surface topographies. Yet, this species is generally a relatively harmless, subcuticular leaf parasite. On leaves, symptoms vary according to the Cephaleuros-host species combination. For C. virescens, leaf spots are usually on the upper leaf surface, raised, velvety in appearance, in shades of orange or brown.

Minor disease

Minor diseases include erythrina gall wasp, blight, basal wilt, etc. Hence diseases are the interactions of a host plant and various organisms (Zhou and Hyde, 2001). Even minor diseases have caused losses of production under special climate conditions. Descriptions of the pathogens and main symptoms are given.

Pollu beetle

Pollu beetle is the most important and a specific pest of Pepper. The adult is a small shiny blue beetle about 2.5 mm in length. Its hind legs are stout and modified for jumping long distances. On receipt of pre-monsoon showers, pepper plants start putting forth new flushes. Then the residual population growing in shaded areas becomes active. Beetle spends its life cycle on new flushes feeding on tender leaves and boring into tender shoots till the plant puts froths spikes. Once the spike appears the beetle moves to the spike. Berries are attacked when they start appearing.

Pathogen: Longitarsus nigripennis (Chrysomelidae: Coleoptera)

The adult is a bluish yellow shining flea beetle. Eggs are laid on the berries and lays 1-2 eggs in each hole, egg period 5-8 days, larval period 30-32 days. Pupation occurs in the soil in a depth of 5.0 - 7.5 cm. Pupal period 6-7 days. The life cycle was completed in 40 - 50 days. Four overlapping generations in a year.

Symptoms: The pollu beetle is a serious disease in black pepper plantations in the plains and at lower altitudes. The grubs bore into the berries of pepper. The infested berries dry up and turn dark in color. Berries are hollow and crumble when pressed. Such hollow berries are called “POLLU” (Empty). Grub may also eat the spike causing the entire region beyond it to dry up. When contents of one berry are exhausted, the grub moves to next and feed continuously. With the appearance of new flushes, beetle lays eggs on them. Emerging grubs bore in to tender shoots and as a result, the tender shoots dry. Beetle also lays eggs on tender leaves, the emerging grubs scrape, and feed on leaves.

Portions of leaves subjected to attack by the grub later dries and are blown away by wind and result in the formation of holes on leaves. Beetle also feeds on leaves resulting in feeding holes. When spikes are formed the beetle lays eggs on the spike. The emerging grubs bore into the spike and the spike beyond the area of damage breaks resulting in "murithiri"(broken spike). When the spike develops and becomes hard the grub feed on the skin of the spike. Damage to spike affects the berry formation badly. When the berries are formed the beetle makes small holes on the berries and lays an egg. Attacked berries become hollow and crumble when pressed. Such hollow berries are called pollu berries.

Erythrina gall wasp

Erythrina stricta Roxb., a quick-growing species with showy red flowers, is grown as a Quadrastichus erythrina – female wasp. the standard for trailing black pepper (Piper nigrum L.) and vanilla (Vanilla planifolia Andr.) throughout south India. Severe incidence of Q. erythrina has been noticed on E. stricta in the plains of Thiruvananthapuram District, Kerala

since April 2005 on a serious proportion. Interestingly, during the same period, the pest was also reported from Hawaii infesting three different species of Erythrina. Similarly, a five-centimeter long piece of galled petiole and tender stem produced up to 51 and 64 wasps respectively. The sex ratio of wasps emerging from galls was highly skewed towards males, with 2.7 males emerging for each female. Severely infected branches appear stunted and bushy. Galled leaves and tender branches finally dry up. As the newly emerging leaves are converted into galls, there is a severe reduction in the number and size of leaves besides complete cessation of growth. Such trees present a scrawny appearance with the malformed and crinkled shoot.

Pathogen: Quadrastichus erythrina Kim, (Hymenoptera: Eulophidae)

According to Kaufman *et al*., (2020) invasive Erythrina Gall wasp (EGW), was first reported from the Mascarene Islands and Singapore in 2003. It was subsequently reported from Tawain, India, American Samoa, China, Thailand, Malaysia, Guam, Philippines, Vietnam, Japan, Hawaii, Mariana Islands, Barbados, Brazil, and Florida, and most recently Central America, within a remarkably short time of the initial detection of the invasion. The worldwide invasion by Q. erythrina appears to have originated from a single source in East Africa and is characterized by low genetic diversity.

Reproduction: Female EGW lay eggs inside new leaves, petioles, stems, flowers, and young seedpods of Erythrina plants. Multiple generations of EGW may be produced each year. It is unclear how the gall wasps survive the period when Erythrina trees drop their leaves, but it is assumed they enter a quiescent state within fallen leaves. Larval feeding induces deformation and swelling of young tissues. Larvae pupate inside the galls and adults emerge from the galls by tunneling through the infested material to the outside (Kaufman *et al*., 2020). A heavy infestation can cause severe defoliation and therefore deterioration of plant health that may lead to plant death.

Symptoms: According to Shylesha *et al*., (2012) the nature of damage observed on E. stricta was similar to those described by Yang *et al*., 2004. Female wasp thrusts eggs into tender tissues of shoots using the exerted ovipositor. Apodous, creamy white larvae develop individually in chambers formed inside the meristematic tissue. The proliferation of tissues in the attacked portion results in gall formation. Galls are formed on the entire developing stem, petiole and leaf lamina with characteristic enlargement and malformation. The mean thickness of galled petioles was 3.1 times more than that of normal. In the case of the tender stem, infestation resulted in the enhancement of mean thickness twice. Multiple galls with layers of larval chambers are formed in the affected portion. Infected leaves fail to attain the normal size and shrivel with thick galls on them. Petioles and tender stem enlarge in thickness and present a curly appearance with knot-like galls on them.

Slow decline

Burrowing nematode disease; toppling disease, blackhead disease (banana); spreading decline (citrus); yellows, slow wilt (black pepper).

Pathogen: Radopholus similis (Nematoda, Tylenchida, Pratylenchidae)

It was first observed by Nathan A. Cobb in necrotic banana roots from Fiji in 1891. The signs of these diseases are the various stages of R. similis observed in soil and plant root samples. All nematode stages are vermiform (wormlike), colorless, and less than 1 mm in length. Adult males and females are different in appearance (sexual dimorphism), the males having poorly developed stylets and a knob-like head caused by an elevated, constricted lip region. Both males and females have long, tapered tails with rounded or indented ends. The male has a sharp, curved spicule (male reproductive organ), enclosed in a

bursa, or sac. Females are between 550 and 880 µm (0.55 to 0.88 mm) in length and about 24 µm in diameter, with well-developed stylets 16 to 21 µm (average 18 µm) long. Males are smaller than females, 500 to 600 µm in length. Juveniles are often present in both root and soil samples and average between 315 to 400 µm in length with stylets 13 to 14 µm long.

Reproduction: Over 350 plant hosts in tropical and subtropical regions including banana, citrus, black pepper, aroids (anthurium, philodendron, taro), ginger, tea, coconut, and other tropical palms. The burrowing nematode is an obligate parasite and needs a living host to survive, though its various stages can move from root to soil and vice versa. It is classified as a migratory endoparasite, completing its life cycle as it tunnels through the root cortex. Females and juvenile stages are infective but males with their weak stylets do not feed. Radopholus similis usually penetrate roots near the tip but can invade along the entire length of the root. They move between cells of the root cortex, feeding on them until the cells collapse and from necrotic passages. In most hosts, R. similis does not damage the central cylinder, though the citrus race reportedly feeds on the phloem, girdling and destroying the stele. Migration and egg-laying are stimulated by nutritional factors: females need healthy tissue to feed on, but eggs are laid in root tissue that quickly decomposes. Females usually reproduce sexually, but can also reproduce without males. This phenomenon was once considered parthenogenesis, but recent studies suggest it might be hermaphrodism. Females lay 4 to 5 eggs per day (2 per day in citrus) for several weeks as they move through the root cortex.

Symptoms: Most soil-borne plant pests and diseases are not evident above ground until they are well established. Early symptoms caused by root-feeding pests are due to impaired water and nutrient uptake. These symptoms include stunted plant growth, decreased vigor and yield, premature leaf drop, and an increased tendency to wilt or dieback during dry periods. Radopholus similis causes a slow decline of many plant species, but symptoms are distinctive in banana and plantain (Musa hybrids and cultivars.), citrus (Citrus spp.), and black pepper (Piper nigrum).

The main symptoms of yellows, or slow wilt disease of black pepper, are pale yellow leaves that droop and then fall from the vine. Other symptoms caused by decreased water and nutrient uptake are slow plant growth, flower drop, and vine dieback. Symptoms are more pronounced during dry periods, but if moisture becomes available early in the disease (e.g. tropical monsoon rains) leaves are replaced and vines appear to recover. In 3 to 5 years, however, the disease will re-emerge, and so the name ‘slow wilt’. Burrowing nematode attacks both young and old plants, so vines replanted in infested soil normally die within 2 years. Thin, white feeder roots have purplish lesions and are quickly destroyed. Lesions are harder to see on older, brown roots, which are slower to rot.

Yellow Mottle virus disease

Piper yellow mottle virus (PYMoV) (genus: Badnavirus) is an important virus infecting black 40 pepper and related species in India and other parts of the World (Bhat *et al*., 2003). Mottle disease caused by viruses is one of the black pepper main diseases and has been recorded in several countries i.e. India, Thailand, Malaysia, Sri Lanka, Brazil, Philippines, and China. This disease is associated with the Piper yellow mottle virus (PYMoV) (Badnavirus: Caulimoviridae) and Cucumber mosaic virus (CMV) (Cucumovirus: Bromoviridae) (Revathy and Bhat, 2017). Both viruses have also been detected on black pepper plantations in Indonesia. The incidence of the disease reached 95% in Bangka and Lampung in 2005 (Lakani, 2006). According to Alif *et al*., (2018), the high incidence of this disease was also observed in Yogyakarta (86 – 93.75%) PYMV and possibly other unidentified viruses have been one of several factors in a

disease complex limiting black pepper production and contributing to black pepper plantation decline in southeast Asia. There have also been reports of a viruslike disorder of black pepper in India and symptoms similar to those described above for PYMV infection were observed previously in India and Indonesia. This suggests that PYMV may occur in black pepper in Southeast Asian countries other than those mentioned above. Black pepper is a perennial vine propagated vegetatively through stem cuttings that favor the build-up of virus concentration over time and the virus moves from one place to another through vegetative propagules. Also, PYMoV is transmitted through seeds.

Pathogen: Badnavirus: Caulimoviridae

The virus, named Piper yellow mottle virus (PYMV), had non-enveloped bacilliform virions averaging 30 x 125 nm in size and containing a double-stranded DNA genome. Piper yellow mottle virus resembles the majority of badnaviruses in having a restricted host range but differs from other badnaviruses in the unusual configuration of a large proportion of its genomic DNA molecules observed by EM and a relative resistance of its extracted genomic DNA to S1 nuclease digestion. The rod-like configuration and resistance to S1 nuclease of some PYMV DNA molecules suggest that these may represent covalently closed, supercoiled molecules.

Symptoms: The affected plant show a diverse range of symptoms such as mosaic, interveinal chlorotic mottle, chlorotic specks, vein clearing, yellow mottling, leaf size reduction and deformation, reduction in internode length, stunting of plants, reduced plant vigor and poor fruit set (Bhat *et al*., 2003).

Ecological Management

The key to sustainable plant disease management is to establish an agro-ecological system that is favorable to plant growth and development at the population level and adverse to pathogen evolution and epidemic development based on interactions among plants, pathogens, vectors and environments (Acosta-Leal *et al*. 2011). This management system includes two main components: multiple goals (high yield, efficiency, good quality, and safety) and dynamic and integrated approaches guided by a comprehensive understanding of the evolutionary ecology of particular host-pathogen interactions. This integrated approach shows great promise in overcoming the problems and challenges associated with current strategies of plant disease management to optimize its economic, ecological, and social benefits.

Prevention Measures

Spraying pesticides to kill pathogens and/or their insect vectors is an inseparable part of plant disease management when other approaches cannot achieve the required level of pathogen population density reduction and epidemic amelioration. However, the use of pesticides in an integrated disease management system is not to eradicate the disease but to control it to the most appropriate extent as guided by ecological and economical thresholds. During pesticide application, factors such as action modes and pathogen resistance should be considered. To increase their efficiency of application and reduce negative impacts on the environment, pesticides should be used in combination with disease forecasts and knowledge of the pathogen population genetic structure (Zhan *et al*. 2015) to determine the best time and frequency of application and to choose the type and utilization dosage of the pesticides. Remedy successes could also be achieved by other approaches than synthetic fungicides such as naturally occurring plant compounds with biological control activity-for example protein y3 that is extracted from edible fungi and other microbes (Bacillus spp.) (Kumar *et al*. 2014). To ensure effective use of such bio-pesticides a better understanding of their properties and application procedure is important as is information about relevant biological features and the transmission mode of pathogens.

For example, adding viral therapeutic agents or biological control agents in 1–2 sprays at the rice seedling and turning green stage can not only reduce viruliferous insect population density but also protect the plant from further infection (Xie *et al*. 1979). Combining pesticides with other biotic and abiotic approaches such as biological agents, soil pH adjustment and UV irradiation has proved to be very effective in long-term control of tomato and lettuce root rot (Lee 2015). Cultural practices including phytosanitation and repeated prophylactic application of copper fungicides are the recommended measures for the management of this disease. Biological control has emerged as an important alternative in managing soil-borne plant diseases in recent years. Pseudomonas spp. have been used extensively as biological control agents against many soil-borne plant pathogens in several crops. Although the integrated soilborne disease management strategies may not eradicate all the pathogenic organisms from the soil, it entails continuous exploration and research for sustainable crop production which will secure a sustainable future for an ever-growing population (Milan *et al*., 2020).

Conclusion

Pepper (Piper nigrum Linn.) (Piperaceae), known as the king of spices is indigenous to India. Here, we have reviewed several major and minor diseases, pests and pathogens, and the symptoms that lead to crop damage and yield loss. These diseases include fungi, algae, viruses, and insects which affect both leaves as well as roots. The diseases are responsible for major yield losses in commercially important crops worldwide. In addition to evaluating the agricultural significance of diseases, it is necessary to develop management and prevention measures that inhibit the growth of pathogens as well as enable the rapid growth of the plant.

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Compliance with Ethical Standards

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Conflict of Interest

Both authors declare that they have no conflict of interest.

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