Plant Pathology & Quarantine 14(1): 98–117 (2024) ISSN 2229-2217
www.ppqjournal.org

Article
Doi 10.5943/ppq/14/1/9

Diseases of Eggplant (*Solanum melongena* L.) and Sustainable Management in Asia

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Aumentado HD, Balendres MA 2024 – Diseases of eggplant (*Solanum melongena* L.) and sustainable management in Asia. Plant Pathology & Quarantine 14(1), 98–117, Doi 10.5943/ppq/14/1/9

Abstract

Eggplant (*Solanum melongena* L.) is one of the most economically important vegetable crops in Asia. It is susceptible to several fungal, bacterial, and viral diseases, negatively affecting eggplant production and profitability. These diseases are Cercospora leaf spot, early blight, powdery mildew, target spot, little leaf disease, Phomopsis blight, fruit rot, Choanephora wet rot, anthracnose, bacterial wilt, Verticillium wilt, Fusarium wilt, Phytophthora blight, fruit rot, and southern blight. This paper reviews the current knowledge of eggplant's major foliar, fruit, and soilborne diseases in Asia. The causal organisms (etiology), associated symptoms, disease epidemiology, economic impact, pathogen distribution, and disease management strategies are discussed. Effective management of eggplant diseases can be achieved through combined early disease detection and monitoring, crop rotation, field sanitation, and resistant or less susceptible eggplant cultivars.

Keywords – anthracnose – bacterial wilt – *Diaporthe* – powdery mildew – Solanaceous crop

Introduction

Eggplant (*Solanum melongena* L.), also called aubergine (in Britain and France) and brinjal (in South Africa and Southern Asia), is a widely grown species from the nightshade family (*Solanaceae*). In 1951, when Vavilov recommended an Indo-Burman origin, India was considered the center of domestication (see Bhaduri 1951, Choudhury 1976, Mace et al. 1999, Doganlar et al. 2002, Daunay 2008, Weese & Bohs 2010, Meyer et al. 2012). The earliest records that provide evidence of the region where eggplant was first domesticated are two millennia old (Meyer et al. 2012). These ancient records exist in India and southern China, supporting another theory that domestication started in China (Bhishagratna 1907, Daunay & Janick 2007). However, these writings describe already-domesticated eggplants, suggesting domestication occurred before (Meyer et al. 2012). In two distinct regions, these ancient records indicate either a far earlier domestication history and subsequent spread from one place to another or multiple domestication events (Meyer et al. 2012), like in many crops (Olsen & Gross 2008).

Eggplant is one of the most economically important vegetable crops cultivated and consumed globally. It is predominantly produced in Asia (94%) (FAOSTAT 2020). China tops the production, accounting for 35.5 million tons of eggplant (FAOSTAT 2020). However, Eggplant production is

Submitted 23 January 2024, Accepted 20 July 2024, Published 24 September 2024
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Accepted reviewer: Kevin D. Hyde

constrained by several abiotic and biotic factors. Among the most difficult to manage are diseases. Fungal, bacterial, and viral pathogens affect leaves, stems, fruits, and roots of plants, leading to a reduction in the potential yield. Yield reduction ranges from 50% to 90%, which may eventually destroy the whole crop (Palo 1938) and lead to monetary losses.

As an important crop mainly produced in Asia, but with worldwide importance and diseases as a major production impediment, this paper synthesizes the current knowledge on the major foliar, fruit, and soilborne diseases of eggplant in Asia (Table 1). Here, we review the etiology, epidemiology, impact, and management strategies for major eggplant diseases and highlight the importance of emerging pathogens in eggplant production.

Table 1. Distribution summary of eggplant foliar, fruit, and soilborne diseases in Asia.

Disease	Pathogen	Country	References
Cercospora leaf spot	*Cercospora melongenae*	China	Tai (1979), Zhuang (2005)
	Cercospora melongenae	India	Gupta & Madaan (1982), Williams (1987), Gautam et al. (2020)
	Cercospora melongenae	Korea	Cho & Shin (2004)
	Cercospora melongenae	Myanmar	Thaung (1984), Williams (1987)
	Cercospora melongenae	Philippines	Teodoro (1937), Chupp (1953), Williams (1987)
	Cercospora melongenae	Taiwan	Hsieh & Goh (1990)
	Cercospora melongenae	Bhutan	Williams (1987)
	Cercospora melongenae	Nepal	Williams (1987)
	Cercospora physalidis	India	Kamal (2010)
	Cercospora physalidis	Sri Lanka	Adikaram & Yakandawala (2020)
	Cercospora solani	India	Kamal (2010)
	Cercospora solani	Myanmar	Thaung (1984)
	Alternaria alternata	China	Tai (1979), Wang & Zang (2003), Zhuang (2005)
	Alternaria alternata	India	Richardson (1990), Raina et al. (2018)
	Alternaria alternata	Pakistan	Shafique et al. (2020)
	Alternaria tenuis	India	Kapoor & Hingorani (1958), Gurunath Rao (1966)
	Alternaria tenuissima	China	Wang & Zang (2003), Zhuang (2005)
	Alternaria tenuissima	India	Raja et al. (2006)
	Alternaria tenuissima	Malaysia	Thaung (2008), Nasehi et al. (2012)
	Alternaria tenuissima	Pakistan	Naqvi & Husain (1959), Ahmad et al. (1997)
	Alternaria solani	China	Guo Y (1993), Rao (1969), Wang & Zang (2003), Zhuang (2005)
	Alternaria solani	India	Saksana (1928), Rao (1969), Gupta & Madaan (1982)
	Alternaria solani	Korea	Cho & Shin (2004)
	Alternaria solani	Pakistan	Ahmad et al. (1997)
	Alternaria solani	Taiwan	Sawada (1959)
	Alternaria solani	Thailand	Giatgong (1980)
Powdery mildew	*Golovinomyces cichoracearum*	Korea	Cho et al. (2004)
	Golovinomyces cichoracearum	South Korea	Cho et al. (2017)
	Erysiphe cichoracearum	Japan	Amano (1986), Farr & Rossman (2021)
	Erysiphe cichoracearum	South Korea	Cho et al. (2017)
	Erysiphe cichoracearum	Korea	Amano (1986), Farr & Rossman (2021)

Table 1 Continued.

Disease	Pathogen	Country	References
	Erysiphe cichoracearum	Saudi Arabia	Amano (1986)
	Erysiphe cichoracearum	Iraq	Amano (1986)
	Erysiphe cichoracearum	Lebanon	Amano (1986)
	Erysiphe cichoracearum	Taiwan	Amano (1986), Yen (1967)
	Erysiphe cichoracearum	Turkey	Amano (1986)
	Golovinomyces orontii	Israel	Voytyuk et al. (2009)
	Erysiphe orontii	India	Paul & Thakur (2006), Amano (1986), Farr & Rossman (2021)
	Erysiphe orontii	Turkey	Braun (1995), Amano (1986), Farr & Rossman (2021)
	Erysiphe polyphaga	India	Sarbhoy et al. (1971), Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	China	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	India	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	Iran	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	Iraq	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	Israel	Amano (1986), Voytyuk et al. (2009)
	Leveillula taurica	Japan	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	Jordan	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	Korea	Farr & Rossman (2021)
	Leveillula taurica	Lebanon	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	Myanmar	Amano (1986), Thaung (2008), Farr & Rossman (2021)
	Leveillula taurica	Pakistan	Amano (1986), Farr & Rossman (2021)
	Leveillula taurica	South Korea	Kwon et al. (1998), Cho et al. (2017)
	Leveillula taurica	Turkey	Amano (1986), Braun (1995)
	Sphaerotheca fuliginea	China	Tai (1979), Amano (1986), Farr & Rossman (2021)
	Sphaerotheca fuliginea	India	Amano (1986)
	Sphaerotheca fuliginea	Japan	Amano (1986)
	Sphaerotheca fuliginea	Taiwan	Amano (1986)
	Sphaerotheca fusca	South Korea	Cho et al. (2017), Lee et al. (2002)
	Podosphaera xanthii	China	Liu et al. (2015)
	Podosphaera xanthii	South Korea	Cho et al. (2017)
	Podosphaera xanthii	Thailand	Meeboon et al. (2016)
Target spot	*Corynespora cassiicola*	India	Singh (1979), Sarbhoy et al. (1971), Sarma & Nayudu (1971), Ram & Lele (1968)
	Corynespora cassiicola	Myanmar	Thaung (2008)
	Corynespora cassiicola	Sri Lanka	Adikaram et al. (2020)
	Corynespora cassiicola	China	Gao et al. (2012)
Little leaf disease	Phytoplasma	India	Kumar et al. (2016)
	Phytoplasma	Japan	Okuda et al. (1997)
	Phytoplasma	Oman	Al Subhi et al. (2011)

Table 1 Continued.

Disease	Pathogen	Country	References
Phomopsis blight and fruit rot	*Phomopsis vexans*	Philippines	Teodoro (1937), Palo (1938)
	Phomopsis vexans	Brunei Darussalam	Peregrine & Ahmad (1982)
	Phomopsis vexans	China	Chi (2007), Luo et al. (2004), Teng (1996)
	Phomopsis vexans	India	Mathur (1979), Mahadevakumar et al. (2017), Islam & Pan (1990)
	Phomopsis vexans	Korea	Cho & Shin (2004)
	Phomopsis vexans	Myanmar	Thaung (2008)
	Phomopsis vexans	Sri Lanka	Adikaram & Yakandawala (2020)
	Phomopsis vexans	Taiwan	Sawada (1959)
	Phomopsis vexans	Saudi Arabia	Abu Yaman & Abu Blan (1972)
	Phomopsis vexans	Bangladesh	Masuduzzaman et al. (2008)
	Phomopsis vexans	Japan	Shishido et al. (2006)
	Phomopsis vexans	Jordan	EPPO (2000)
	Phomopsis vexans	Malaysia	Thompson & Johnston (1953)
Choanephora wet rot/soft rot	*Choanephora cucurbitarum*	Brunei Darussalam	Peregrine & Ahmad (1982)
	Choanephora cucurbitarum	China	Tai (1979)
	Choanephora cucurbitarum	India	Gupta & Madaan (1982), Das et al. (2017)
	Choanephora cucurbitarum	Malaysia	Turner (1971)
	Choanephora cucurbitarum	Pakistan	Ahmad & Khalid (1997)
	Choanephora cucurbitarum	Korea	Kwon & Jee (2005)
	Choanephora infundibulifera	India	Das et al. (2017)
	Choanephora trispora	Brunei Darussalam	Peregrine & Ahmad (1982)
Anthracnose	*Colletotrichum gloeosporioides*	India	Sharma et al. (2013)
	Colletotrichum melongenae	Korea	Cho & Shi, (2004)
	Colletotrichum acutatum (*C. fioriniae*)	South Korea	Xu et al. (2018)
	Colletotrichum coccodes	India	Mathur (1979)
	Colletotrichum coccodes	Korea	Cho & Shin (2004)
	Colletotrichum dematium	India	Mathur (1979), Sarbhoy et al. (1971), Sarbhoy & Agarwal (1990)
	Colletotrichum dematium	Taiwan	Matsushima (1980)
	Colletotrichum circinans	Korea	Cho & Shin (2004), Farr & Rossman (2018)
	Colletotrichum truncatum (*C. capsici*)	Brunei Darussalam	Peregrine & Ahmad (1982)
	Colletotrichum truncatum	India	Gupta & Madaan (1982), Mathur (1979), Sarbhoy & Agarwal (1990), Sharma et al. (2013)
	Colletotrichum truncatum (*C. capsici*)	Malaysia	Williams & Liu (1976)
	C. truncatum	Sri Lanka	Adikaram & Yakandawala (2020)
	C. truncatum	Thailand	Hyde et al. (2018)
Verticillium wilt	*Verticillium dahlia*	China	Zhuang (2005)
	Verticillium dahlia	Iran	Rafiei et al. (2018)

Table 1 Continued.

Disease	Pathogen	Country	References
	Verticillium dahlia	Japan	Koike et al. (1996)
	Verticillium dahlia	Korea	Kim et al. (2000), Cho & Shin (2004)
	Verticillium albo-atrum	China	Tai (1979), Zhuang (2005)
Fusarium wilt	*Fusarium oxysporum* f. sp. *melongenae*	Japan	Matuo & Ishigami (1958)
	Fusarium oxysporum f. sp. *melongenae*	Turkey	Altinok (2005)
		India	Cherkupally et al. (2017)
	Fusarium oxysporum f. sp. *melongenae*	Iran	Safikhani et al. (2013)
	Fusarium oxysporum	China	Tai (1979, Zhuang 2005)
	Fusarium oxysporum	Korea	Cho & Shin (2004)
	Fusarium solani	India	Richardson (1990), Sarbhoy & Agarwal (1990)
	Neocosmospora solani	Sri Lanka	Adikaram & Yakandawala (2020)
Phytophthora blight and fruit rot	*Phytophthora melongenae*	Philippines	Teodoro (1937)
	Phytophthora melongenae	Taiwan	Anonymous (1979)
	Phytophthora melongenae	Thailand	Giatgong (1980)
	Phytophthora nicotianae	China	Erwin & Ribeiro (1996), Tai (1979), Yu (1998)
	Phytophthora nicotianae	Thailand	Erwin & Ribeiro (1996), Chowdappa et al. (2016)
	Phytophthora nicotianae	Indonesia	Erwin & Ribeiro (1996)
	Phytophthora nicotianae	Iran	Erwin & Ribeiro (1996)
	Phytophthora nicotianae	Japan	Rahman et al. (2014)
	Phytophthora nicotianae	Korea	Cho & Shin et al. 2004)
	Phytophthora nicotianae	Malaysia	William & Lui (1976), Turner (1971), Drenth & Guest (2004)
	Phytophthora nicotianae	Philippines	Teodoro (1937), Drenth & Guest (2004)
	Phytophthora nicotianae	Taiwan	Hall (1993), Erwin & Ribeiro (1996)
	Phytophthora parasitica	Thailand	Giatgong (1980)
	Phytophthora parasitica	Taiwan	Erwin & Ribeiro (1996)
	Phytophthora infestans	China	Tai (1979)
	Phytophthora infestans	India	Sarbhoy et al. (1971)

Foliar Diseases

Cercospora Leaf Spot/Frog-Eye Spot

Cercospora species cause Cercospora leaf spot or frog-eye spot of eggplant and is a major problem for growers (Chupp 1953, Farr et al. 1989). Initially, the spots are small, circular to oval chlorotic that develop to chlorotic, angular to irregular in shape, later turning into grayish-brown and concentrically marked with light to dark tan centers (Kumar et al. 2020, Welles 1922). Concentric rings of diseased tissue gradually expand. The tissue may crack and drop out as the lesion dries, resulting in a shot-hole condition. Elliptical to oval lesions occur on the leaf blades, veins, and petioles (Kumar et al. 2020). Cercospora leaf spot infects and develops favorably in high relative humidity and wet leaves. Thus, it becomes prevalent during the rainy season (wet weather, continuous plant wetness). It survives in plant debris or soil for at least a year (Srivastava & Nelson 2012).

The pathogen affects eggplant grown in several Asian countries. It is a major problem for large-scale growers and backyard gardeners (Gonsalves et al. 1994, Kranz & Werner 1978, Chupp 1953), resulting in severely infected leaves, premature drop-off, and reduced growth of the plant, resulting in yield loss (Chupp 2006).

Management of Cercospora leaf spot in eggplant includes using disease-free planting materials, proper field sanitation, minimizing plant injury, removing and destroying infected leaves and plant parts, and proper plant maintenance (Kumar et al. 2020). Proper plant spacing for eggplant may improve air circulation and drying of wet leaves. Avoiding over-irrigation and maintaining adequate fertilization also helps control the disease (Srivastava & Nelson 2012).

Early Blight

Several *Alternaria* species cause early blight or Alternaria leaf spots. The disease affects all aboveground plant parts of eggplant throughout the growing season. Initially, it causes characteristic leaf spots with concentric rings on older leaves, primarily irregular. It coalesces to cover a large leaf blade area. The spot center can appear light tan, with a dark brown ring and chlorotic halo. It split into the later developmental stages (Shafique et al. 2020). These lesions on eggplant are lighter in color, and the concentric ring pattern may not be as noticeable in tomato. Severely affected leaves result in leaf senescence, which exposes the fruit and makes it more likely to be damaged by sunscald.

The pathogen survives on crop debris in the soil from season to season and grows well in warm, wet conditions. Early blight occurs nearly every year mainly due to the soil-borne fungi survival, cultivation of susceptible varieties, and favorable environmental conditions (Khan et al. 2003). The spores are carried and spread by winds and splashing water. *Alternaria* sp. is an opportunistic pathogen and causes several plant diseases (Reddy et al. 2002). Disease incidence can average approximately 30% in severely infected regions of eggplant fields and greenhouses (Nasehi et al. 2012). Affected fruit may not completely cause severe yield losses (Raja et al. 2006). Early blight or Alternaria leaf spot is reported under various *Alternaria* species in eggplant in Asian countries.

The best management approach to early eggplant blight is preventive measures. Once the disease is established in the plant, it is difficult to eliminate. These measures include using disease-free seed/ planting materials, proper plant spacing, minimizing plant injury, removing and eradicating infected plant parts and crop debris, maintaining plant vigor, and using resistant and tolerant cultivars.

Powdery Mildew

Eggplant is a common host of powdery mildew species, including *Golovinomyces cichoracearum* (also known as *Erysiphe cichoracearum* and *Sphaerotheca fuliginea* (syn. *Podosphaera xanthii*) and *Podosphaera fusca* (McCreight 2006). Symptoms in eggplants are initially characterized by white patches on the lower surface of the leaf, petioles, and sepals, then progress to the upper side to cover the entire surface of the leaf with whitish, talcum-like powder mycelium/ pustules that later turn into brown, leaves become shriveled and necrotic, and in advance stages leaf defoliation, stunted plant growth, and eventually death of plants. In powdery mildew outbreaks, the lesions coalesce and cause severe defoliation, debilitating the disease and resulting in yield loss. Several eggplant powdery mildew species have been reported in Asia.

Management of eggplant powdery mildew includes maintaining field sanitation, removal and destruction of infected plant parts by burning, proper plant spacing, overcrowded plants pruning to increase air circulation, and avoiding overhead watering/irrigation (Thurston 1998, Ploetz et al. 1998). Chemical fungicides (e.g. triadimefon, triforine, fenarimol) (Ciccarese & Cirulli 1980), metalaxyl, mancozeb, chlorothalonil (Ramathani 2018), potassium bicarbonate, and sulfur-based spray products are also used as last resort for powdery mildew management (Ramathani 2018). Nevertheless, utilizing resistant plants (e.g. Datar 1976, Bubici & Cirulli 2008) is still the most efficient and durable management strategy for controlling powdery mildew.

Target Spot

The target spot pathogen, *Corynespora cassiicola*, is common in the tropics and subtropics. It infects the leaves, stems, roots, and flowers of over 500 plant species (Smith et al. 2007) from over 70 tropical and subtropical countries (Farr et al. 2007). Initial target spot symptoms may resemble bacterial spots (*Xanthomonas* spp.) (Schlub et al. 2007). Lesions coalesce, creating large blighted areas on the leaves that cause premature defoliation (MacKenzie et al. 2018). The disease is more common on mature leaves and dominant in the inner canopy that, causes unnoticeable blighting and defoliation (Schlub et al. 2007).

Corynespora cassiicola may survive in infected plant debris for more than two years with favorable pathogen growth conditions, including high humidity (16–44 h) and warm temperature (25–32°C). The pathogen spores can spread through infected seeds, wind, and plant debris (Daughtrey et al. 1995). They can be rain-dispersed (MacKenzie et al. 2018) and optimally released mid-morning (Pernezny & Simone 1993).

If not managed well, target spot infection results in lower crop yield and monetary loss. Management of target leaf spot of eggplant includes using disease-free plants, good field sanitation, removal and destruction of heavily infected leaves, removal of weeds as an alternate host, and adequate plant spacing to lessen periods of leaf wetness and good air circulation between plants.

Little Leaf Disease

Little leaf disease is caused by phytoplasma/mycoplasma, which is transmitted by leafhoppers and planthoppers/jassids such as *Amrasca devastans* (syn. *Empoasca devastans*) and *Cestius phycitis* (formerly *Hishimonus phycitis*; *Eutettix phycitis*) (Chen et al. 2002). It is one of the most important diseases in eggplant that can result in yield loss. It usually appears in a 1–2-month-old plant. The infected plants show stunting, little leaves, shoots proliferating, and reduced leaf size (Rao et al. 2010), making the bushy appearance of the eggplant. Infected plants do not form flowers; in case of late infection, fruit development is stopped, and hardened fruit fails to mature. Eggplant phytoplasma disease has been reported in areas where overlapping crop cycles and weeds and high populations of leafhoppers exist (Rao & Kumar 2017). The disease has also been reported to be transmitted by grafting (Saranya & Umamaheswaran 2014).

Eggplant phytoplasma-associated diseases can cause yield losses from 40–100% (Mitra 1993, Rao & Kumar 2017, Rao et al. 2010). The damage is more severe at an early infection, which could result in no plant fruiting. When the infection is latent, fruits become malformed and shriveled. Root development is also diminished in the infected plant. So far, this phytoplasma-associated disease of eggplant in Asia has been reported in India (Kumar et al. 2016), Japan (Okuda et al. 1997), and Oman (Al Subhi et al. 2011). Management of little leaf disease of eggplant includes eradicating weeds, which serve as alternate hosts, controlling the vectors, planthoppers, and leafhoppers (FAO 2003), and using resistant cultivars (e.g. Jyani et al. 1995).

Fruit Diseases

Phomopsis Blight and Fruit Rot

Blight caused by *Phomopsis vexans* (syn. *Diaporthe vexans*) is one of the most destructive fruit diseases (Singh 1999). The disease on stems and leaves reduces fruit size and weight and causes plant death. Initial symptoms include minute sunken spots surrounded by a brownish halo. Spots later coalesce and form larger lesions, and concentric rings may appear. The larger lesion could rot, and conidiomata often develop, which could cover the rotten fruit area. Disease development is favored when conditions are hot and humid, with an optimum relative humidity of greater than 55% (Chaudhary & Hasija 1980). Spore germination is best at 27°C, and pycnidia formation is highest between 30–35°C (Pawar & Patel 1957). Initially, seedlings in contact with inoculum in the soil may exhibit damping-off or seedling blight. Initial leaf infection increases inoculum pressure for subsequent leaf blight and fruit rot disease development (Singh 1992).

Fruit rot is the most destructive stage of the disease that could result in fruit size and weight reduction. Crop productivity and yield are severely affected, reducing crop value by up to 30% (Pandey 2010). The pathogen is reported widely in the following Asian countries and regions: Philippines (Teodoro 1937, Palo 1938), Brunei Darussalam (Peregrine & Ahmad 1982), China (Teng 1996, Luo et al. 2004, Chi 2007), India (Mathur 1979, Islam & Pan 1990, Mahadevakumar et al. 2017), Korea (Cho & Shin 2004), Myanmar (Thaung 2008), Sri Lanka (Adikaram & Yakandawala 2020), Taiwan (Sawada 1959), Saudi Arabia (Abu Yaman & Abu Blan 1972), Bangladesh (Masuduzzaman et al. 2008), Japan (Shishido et al. 2006), Jordan (EPPO 2000), Malaysia (Thompson & Johnston 1953).

Management of Phomopsis blight of eggplant includes using disease-free seeds and planting materials, burning crop debris, and burying it by deep plowing (Singh 1987), and crop rotation of at least three years can reduce the inoculum in the soil (Sherf & MacNab 1986). Using antagonistic *Pseudomonas fluorescens* and *Trichoderma harzianum* as seed and spray treatments is effective against the pathogen (Srinivas et al. 2005). Chemical fungicides, carbendazim (Mohanty et al. 1994, Beura et al. 2008), and tebuconazole (Manna et al. 2004), are used as last resort to control the disease. Nevertheless, resistant plants are still the most efficient disease management approach (e.g. Kalda et al. 1976, Datar & Ashtaputre 1988, Ren & Zhang 1993, Pandey et al. 2002).

Choanephora Wet Rot/Soft Rot

Choanephora wet rot of eggplant is caused by *Choanephora cucurbitarum* and other *Choanephora* species. Initially, soft rot symptoms on fruit are water-soaked. Then, the diseased tissues, when the disease condition is favorable, rot rapidly (Kwon & Jee 2005). The affected tissues turn dark brown, shrivel, and collapse, causing the stems to fall. In the advanced stages, the plant becomes completely necrotic. Most infected fruits show severe inner tissues and are commonly covered with whitish mycelia and tall sporangiophores produced on the lesions (Turkensteen 1979). The symptoms are usually similar to soft rot-causing fungi, including *Rhizopus* spp. or *Mucor* spp. (Kwon & Jee 2005).

The pathogen penetrates mainly through wounds caused by insect or mechanical damage and crops poorly adapted to a hot and humid climate (Turkensteen 1979, Kwon & Jee 2005). The warmer and skewed rainfall distribution pattern and an increase in the average relative humidity in the area increase the disease's emergence and severity (Das et al. 2016). Annual yield losses are dependable and highly variable by seasons and prevailing environmental conditions. Losses are most severe and greatest in predominantly warm and moist conditions. It is reported in eggplant in the following Asian countries: *Choanephora cucurbitarum* in Brunei Darussalam (Peregrine & Ahmad 1982), China (Tai 1979), India (Gupta & Madaan 1982, Das et al. 2017), Malaysia (Turner 1971), Pakistan (Ahmad & Khalid 1997), and Korea (Kwon & Jee 2005); *Choanephora infundibulifera* in India (Das et al. 2017); *Choanephora trispora* in Brunei Darussalam (Peregrine & Ahmad 1982).

Choanephora wet rot management includes planting in well-drained soils, avoiding overhead irrigation, avoiding excessive plant populations, using proper plant spacing for adequate air circulation between plants, and practicing crop rotation (Kucharek 1999).

Anthracnose

Anthracnose of eggplant caused by *Colletotrichum gloeosporioides* is a common fungal disease in eggplant (Madiera & Reifschneider 1987, Fernandes et al. 2002, Sharma et al. 2013). Several *Colletotrichum* species have been associated with eggplant fruit anthracnose, including *C. fioriniae, C. coccodes, C. circinans,* and *C. truncatum* (Farr & Rossman 2021). Symptoms initially appeared as dark, round, and water-soaked spots, gradually expanding and damaging the whole fruit (Xu et al. 2018). The spots become sunken and dark and appear in ripe and unripe fruits. The black fungal bodies exude gelatinous pink spore masses in humid and warm weather. In warm weather, the fungus and soft rot bacteria enter the fruit skin and spread internally, creating a soft decay that leads to the rotting of the whole fruit and falling to the ground. Some *Colletotrichum* species are seed-borne and live well saprophytically on dead plant debris and can disperse their ascospores via air transmission (Nicholson & Moraes 1980) and conidia via water-splash that may carry the fungus asymptomatically (Freeman et al. 2001). The fungus enters a necrotrophic phase, resulting in the significant death of plant cells and the advancement of pathogenic lesions.

The pathogen causes significant yield loss and decreases the number of marketable fruits due to fruit decay and leaf damage in eggplant (Freeman et al. 1998, Gopalkrishnan & Prakasam 2007), the most destructive fungal disease. The latent infection or delayed inception of anthracnose symptoms leads to significant post-harvest losses, with seemingly healthy crops deteriorating in storage (Prusky & Plumbley 1992). Different *Colletotrichum* species are causing eggplant anthracnose in the following Asian countries and regions: *Colletotrichum gloeosporioides* in India (Sharma et al. 2013), and Korea (*C. melongenae*; Cho & Shin 2004); *Colletotrichum acutatum* (*C. fioriniae*) in South Korea (Xu et al. 2018); *Colletotrichum coccodes* in India (Mathur 1979) and Korea (Cho & Shin 2004); *Colletotrichum dematium* in India (Sarbhoy et al. 1971, Mathur 1979, Sarbhoy & Agarwal 1990), Taiwan (Matsushima 1980), and Korea (Cho & Shin 2004, Farr & Rossman 2018); and *Colletotrichum truncatum* in Sri Lanka (Adikaram & Yakandawala 2020) and Thailand (Hyde et al. 2018), India (*C. capsici:* Gupta & Madaan 1982, Mathur 1979, Sarbhoy & Agarwal 1990, Sharma et al. 2013), and Malaysia (*C. capsici:* Williams & Liu 1976).

Management of eggplant fruit anthracnose includes using disease-free, certified seeds and planting materials, planting in well-drained soil, removal and destruction of heavily infected plants and crop residues by burning, minimizing fruit injury, and use of drip irrigation instead of overhead irrigation to minimize the disease spread (Nzila 2014). Chemical seed treatments (e.g., benomyl and chloroxylenol), fungicides such as propineb (Fournet 1973), maneb (Smith 2000), and mancozeb are used to prevent the onset of the disease (Nzila 2014).

Soilborne Diseases

Bacterial Wilt

The bacterial pathogen *Ralstonia solanacearum* species complex (RSSC) causes bacterial wilt and is characterized by foliage's sudden wilting. It is one of Asia's top five eggplant diseases (Elphinstone 2005). *Ralstonia solanacearum* was first reported in the Philippines in 1918 by Reinking. Generally, symptoms occur as browning of the vascular system (Gota 1992). It attacks plants via wound sites and natural openings on roots, invades cortical tissue, multiplies rapidly within the xylem tissue, and successfully clogs the water conduction system, causing wilting symptoms (Meng 2013, Nakaho et al. 2004). The youngest leaves are the first to exhibit leaf drooping or wilting symptoms when the day is warm. This is followed by sudden plant wilting if prevailing conditions are favorable for the pathogen activity. The cut stem of an infected plant exudes white or yellowish viscous ooze (Champoiseau et al. 2009). It is typically raised fluidal, pinkish colonies in TZCA medium (Dela Cueva et al. 2019). In later stages, plants fail to recover, turn yellow and brown necrotic, and die. Sometimes, brown streaks on the stem can be observed on the plant's base, leaves have a bronze tint, and the petioles wilt.

The pathogen enters through root lesions/ wounds induced during transplanting and cultivation, as well as by nematodes and insects (Kelman & Sequeira 1965). The bacteria colonize the xylem, where they adhere by polar attraction to the vessel walls (Charkowski et al. 2020). High incidence is brought by high soil moisture and rainy seasons. Blocking the vessels by a bacterial extracellular polysaccharide (EPS) is the primary cause of wilting (Charkowski et al. 2020). It can be spread in irrigation water, infected plant material, and contaminated soil or field and equipment (Hayward 1991, Louws et al. 2010). Infested water and soil movement contribute significantly in the field than seed transmission.

Bacterial wilt caused by *Ralstonia solanacearum* (Yabuuchi et al. 1995) species complex (formerly *Pseudomonas solanacearum* is described as one of the most destructive plant pathogens mainly in tropical and subtropical parts of the world (Buddenhagen & Kelman 1964, Hayward 1991). In the Philippines, Agati (1949) projected losses of solanaceous crops, including eggplant, with 30 to 80% yield losses. In India, 38–100% bacterial wilt infection in eggplant was detected from seeds (Chatterjee et al. 1994).

Disease management of bacterial wilt remains challenging due to the ability of the bacteria to survive in deep soil (Mansfield et al. 2012, Imada et al. 2016). Eggplant grafted onto resistant *Solanum* species (Mochizuki & Yamakawa 1979) significantly reduced yield loss by 90% (Lum & Wong 1976). Since chemical control is ineffective, prevention and management largely depend on the quality and pathogen-free planting material. Moreover, innate resistance and tolerant plants (e.g. Chaudhary 1999, Mondal 1991) are still the cheapest and most effective management strategies to combat bacterial wilt (Hayward 1991). Disinfection of farming tools and equipment is also essential in preventing and minimizing the spread of the disease.

Verticillium Wilt

Verticillium wilt in eggplant is caused by *Verticillium dahliae* and *Verticillium albo-atrum* (Tai 1979, Zhuang 2005). It is a vascular disease. Likewise, the Fusarium wilt provokes vessel browning and foliar wilting, which is sometimes difficult to diagnose. Common symptoms usually appear around the anthesis, or flowering stage, which includes defoliation and unilateral wilting, usually in the oldest shoots and leaves as the invasion is acropetal (Fradin & Thomma 2006), then developed V-shaped yellowing, brown discoloration in the stem and root, and eventually death of plants.

Generally, this soilborne pathogen intensifies with warm sunny weather, and slightly higher temperatures and heavy clay soils are preferred for disease development. *Verticillium dahliae* is favored by higher temperatures than *V. albo-atrum*, as it can be deduced from its spatial distribution (Fradin & Thomma 2006). Microsclerotia is capable of long-term survival (up to 15 years) without contact with the host plant. The disease is spread by contaminated soil in which the fungus enters the plant through the roots to the vascular system. It can also be transported using infected seed or plant materials, wind or water, tillage operations, tools, and farm machinery.

Verticillium wilt is among the most destructive diseases that result in significant yield loss of up to 50% (Blestos et al. 1997), which includes reduced fruit quality and yield (Blestos et al. 1999). It affects eggplant in the following Asian countries: *V. dahliae* in China (Zhuang 2005), Iran (Rafiei et al. 2018), Japan (Koike et al. 1996), and Korea (Kim et al. 2000, Cho & Shin 2004); and *V. albo-atrum* in China (Tai 1979, Zhuang 2005).

Verticillium wilt disease of eggplant is challenging to control due to the long viability of the pathogen's resting structures. It also affects a broad host range, and fungicides are often ineffective once they enter the xylem, comparable to other soilborne diseases, e.g., bacterial wilt (Mansfield et al. 2012, Imada et al. 2016). Currently, the best way to prevent Verticillium disease is the utilization of resistant cultivars. Studies on grafting eggplant on resistant tomato rootstocks found effective control for the disease (Ginaux & Douple 1985, Lockwood et al. 1970). The wild species *Solanum torvum* and *S. sismbriifolium* are resistant to Verticillium wilt (Alconero et al. 1988, Sakata et al. 1989) and, likewise, susceptible plants that were grafted on the rootstock of *S. integrifolium* revealed with competent results (Oda 1995).

Fusarium Wilt

Fusarium wilt in eggplant, caused by *Fusarium* species, is a soilborne disease that exhibits yellowing of the leaves followed by dropping of leaves and apical shoots, which leads to wilt of the whole plant (Khan et al. 2019, Safikhani et al. 2013) and cause severe damping-off in seedlings (Suryanto et a. 2010). Infected stems show dark brown to black cankers, which may be soft. White-cottony fungal mycelia may also be observed on infected plants, and the roots may become water-soaked. The most pronounced symptom in eggplant is epinasty of leaves and partial stunting, which induces vascular disorders, vessel browning, and subsequent wilting and death of the plants' aboveground parts (Altinok 2005). The pathogen affects and anchorages young roots, growing, developing, and spreading in root and stem vessels, obstructing water and nutrient transport (Miller et al. 1986).

The pathogen can be dispersed from one area to another through several manners: infected planting materials and seeds, farm tools, and machinery, mainly when used in the infected soils and later used in healthy fields. Lack of appropriate drainage or overwatering could help spread the pathogens and hasten the disease development. The disease worsens when plants exhibit stress due to abiotic factors such as high-temperature stress, fertilizer-induced root injury, and under and over-irrigation (Okungbowa & Shittu 2012). Symptoms on the stem decrease the fruit quality and quantity of eggplant (Fayzan 2012), causing up to 40–50% yield loss in eggplant production (Thompson 2010), which leads to economic losses (Bondad-Reantaso et al. 2005). It is reported to affect eggplants in Asian countries caused by various *Fusarium* species: *F. oxysporum* f. sp. *melongenae* was first in Japan (Matuo & Ishigami, 1958). Later, in Turkey (Altinok 2005), India (Cherkupally et al. 2017), and Iran (Safikhani et al. 2013); *Fusarium oxysporum* in China (Tai 1979, Zhuang 2005) and Korea (Cho & Shin 2004); *Fusarium solani* in India (Richardson 1990, Sarbhoy & Agarwal 1990); *Neocosmospora solani* in Sri Lanka (Adikaram & Yakandawala 2020).

Fusarium wilt management includes chemical, biological, and cultural control. Several chemical fungicides (carbendazim, prochloraz, and bavistin) have been used to suppress the disease (Alam et al. 2010). *Penicillium* spp., *Streptomyces griseoviridis*, *Trichoderma harzianum*, *T. asperellum*, and *T. koningii*and have been used as biological control agents (Osuide et al. 2002, Syed et al. 2010, Borrero et al. 2011). Nevertheless, utilizing resistant cultivars is still the best approach to management as well as maintaining good agricultural practices (i.e., sanitation, proper irrigation, avoidance of contamination, use of disease-free seeds and planting materials) to reduce the disease incidence (Jones & Woltz 1981, AVRDC 2005).

Phytophthora Blight and Fruit Rot

Phytophthora fruit rot caused by *Phytophthora melongenae* and *Phytophthora parasitica* is another destructive soilborne disease of eggplant in the Philippines (Erwin & Ribeiro 1996). It causes leaf, stems, and fruit blight of many solanaceous hosts, including eggplant (Erwin & Ribeiro 1996). It is widespread in areas where most fields are infected amid intermittent spraying of fungicides (Alberto & Sanogo 2017). Fruit rot results from the initial infection of the fruit tip near the soil line. Under favorable conditions and dense planting, a fungal mycelium appears in the lesions (Alberto & Sanogo 2017) and ultimately causes serious damage and yield loss.

Several studies reported the role and importance of water management in spreading Phytophthora diseases. Propagules such as zoospores and chlamydospores are often recovered from irrigation water. They are easily dispersed in non-infested areas (Bush et al. 2003). Chlamydospores contribute to the long-term survival of the pathogen in the absence of host plants, which have been reported to last up to six years (Gallup et al. 2006). The pathogen is most active in moist and warm weather.

Fruit rot caused by *P. nicotianae*, now *P. parasitica* (Erwin & Ribeiro 1996), was first reported in the Philippines by Ocfemia (1925), causing 25–75% infection in eggplants. It is reported in several countries and regions in Asia: Philippines (Ocfemia 1925, Teodoro 1937, Drenth & Guest 2004), Thailand (Giatgong 1980), China (Tai 1979, Erwin & Ribeiro 1996, Yu 1998), India (Erwin & Ribeiro 1996, Chowdappa et al. 2016), Indonesia (Erwin & Ribeiro 1996), Japan (Rahman et al. 2014) Korea (Cho & Shin 2004), Malaysia (William & Lui 1976, Turner 1971, Drenth & Guest 2004), Taiwan (Hall 1993, Erwin & Ribeiro 1996).

Management of the Phytophthora blight and fruit rot disease includes using disease-free planting materials, proper land preparation, deep plowing of soil to allow decomposition of crop debris and weed residues, soil solarization, and crop rotation.

Southern Blight/Sclerotium Wilt/Foot and Collar Rot

Athelia rolfsii (syn. *Sclerotium rolfsii)* has been associated with foot and collar rot. The pathogen primarily attacks the stem and invades other plant parts near the soil. Severe infection could lead to chlorosis and could result in lodging and death of plants. Pathogen growth is favored by pH levels at 3.0–5.0, rain, dense planting, and temperatures between 25 and 35 °C. It can be spread in undecomposed crop residue, running water, infested soil, agricultural tools and machinery, infected seedlings, sclerotia among the seeds, in the soil, and in plant debris. The pathogen is generally limited to the soil's upper 5 to 7 cm. It will not survive at a lower level.

All growth stages of plants (from seedling to fruiting stage) are susceptible. Losses differ from light and periodic to the almost destruction of the plant. The pathogen kills host tissue before penetration and subsists on the dead plant tissue. It is reported in eggplant in the Philippines (Teodoro 1937) and Korea (Cho & Shin 2004).

Like in other soilborne diseases, the management of southern blight of eggplant necessitates a continuous management approach. This includes field sanitation, removal and destruction of infected plants and plant debris, crop rotation with non-hosts or less susceptible crops (i.e., corn, onion, and peanuts), proper drainage, deep plowing, and proper land preparation to bury sclerotia, and the use of botanical sprays aid to reduce the disease incidence.

Conclusion

Eggplants are an important part of the vegetable industry throughout the world, with Asia is the top producer and exporter. However, during cultivation, eggplant is attacked by various diseases caused by several fungal, bacterial, and viral pathogens, significantly reducing its potential yield. Farmers lose millions annually due to these diseases. Thus, a thorough understanding of the etiology, epidemiology transmission, distribution, and economic impact of the disease is necessary to reduce the probability of invasion, establishment, growth, damage, and losses brought by these pathogens. Furthermore, knowledge of the appropriate and efficient deployment of production practices, on-farm management tools, using clean/disease-free seeds and planting materials, planting in healthy soils, sanitation, cultural practices, biological management, chemical management, and the use of tolerant and resistant cultivars is essential for effective disease management of eggplant.

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