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Fungi causing diseases in Plants

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ABSTRACT

Fungi constitute the largest number of plant pathogens and are responsible for a range of serious plant diseases. Most vegetable diseases are caused by fungi. They damage plants by killing cells and/or causing plant stress. Sources of fungal infections are infected seed, soil, crop debris, nearby crops and weeds. Fungi are spread by wind and water splash, and through the movement of contaminated soil, animals, workers, machinery, tools, seedlings and other plant material. They enter plants through natural openings such as stomata and through wounds caused by pruning, harvesting, hail, insects, other diseases, and mechanical damage.

Some of the fungi are responsible for foliar diseases – Downy mildews; Powdery mildews; and White blister are some of the highly prevalent foliar diseases. Other fungi – Clubroot; *Pythium* species; *Fusarium* species; *Rhizoctonia* species; *Sclerotinia* and *Sclerotium* species – are soilborne diseases.

Some fungal diseases occur on a wide range of vegetables. These diseases include *Anthracnose; Botrytis* rots; Downy mildews; *Fusarium* rots; Powdery mildews; Rusts; *Rhizoctonia* rots; *Sclerotinia* rots; *Sclerotium* rots. Others are specific to a particular crop group, e.g. Clubroot (*Plasmodiophora brassicae*) in brassicas, Leaf blight (*Alternaria dauci*) in carrots, and Red root complex in beans.

Keywords: fungi, diseases, plants, foliage, seeds, fruits, vegetables, blights, rots

I. INTRODUCTION

The fungi represent an extremely large and diverse group of eukaryotic microorganisms. The cells, which contain a membrane-bound nucleus, are devoid of chlorophyll and have rigid cell walls. Fungi often have a plantlike vegetative body consisting of microscopic branching threadlike filaments of various lengths, called hyphae (singular hypha), some of which extend into the air while others penetrate the substrate on which they grow. The hyphae are arranged into a network called a mycelium. It is the mass of the mycelium that gives fungal growth its characteristic "cottony" or "fuzzy" appearance. Fungi reproduce by a variety of methods, both asexual and sexual. They produce many kinds of spores in very large numbers. For example, the colour of a moldy piece of bread is due to the colour of a massive number of microscopic mold spores[1,2]

In general, a fungal infection can cause local or extensive necrosis. It can also inhibit normal growth (hypotrophy) or induce excessive abnormal growth (hypertrophy or hyperplasia) in a portion of or throughout an entire plant.[3,4] Symptoms associated with necrosis include leaf

spots, blight, scab,rots, damping-off, anthracnose, dieback, and canker. Symptoms associated with hyperplasia include clubroot, galls, warts, and leaf curls.In some instances, the fungus infecting the plant may produce growth or structures on the plant, stems, or leaves such as masses of mycelium or aggregates of spores with a characteristic appearance. These developments are referred to as signs of infection, in contrast to symptoms, which refer specifically to the plant or plant tissue.[5,6]

Some examples of common fungal diseases of vegetable crops are provided in the table below with some typical symptoms.

Fungal disease	Factors conducive to spread	Crops affected	Symptoms
White blister/White rust (*Albugo candida*)	Optimum conditions for disease development are 3-4 hours in mild temperatures (6-24?C).	Brassicas (including Asian leafy brassicas).	White blisters and swellings on leaves and heads of affected plants; blisters consist of masses of white dust-like spores; up to 100% losses have been reported.
Downy mildews (individual species damage particular crop families)	High humidity, leaf wetness and cool to mild temperatures (10-16 °C).	Wide host range including onions; peas; lettuce; celery; spinach; kale; herbs; cucurbits; brassicas; Asian leafy brassicas.	Symptoms usually begin with yellowish leaf spots which then turn brown; downy growth appears on underside of leaves.
Powdery mildews (some species are restricted to particular crops or crop families)	Moderate temperatures (20-25?C); relatively dry conditions (unlike downy mildews).	Wide host range and very common, especially in greenhouse crops: cucumber; melons; pumpkin; zucchini;parsnip; beetroot; potato; herbs; peas; bitter melon;tomato; capsicum; Brussels sprouts; cabbage; swedes.	Small, white, powdery patches on most above-ground surfaces; usually observed first on undersides of leaves but eventually cover both surfaces; affected leaves become yellow, then brown and papery and die.
Clubroot (*Plasmodiophora brassicae*)	Warm weather; acidic soil (pH less than 7); high soil moisture.	Brassicas (including Asian leafy brassicas).	Plants are yellow and stunted and may wilt in hotter parts of the day; large malformed 'clubbed' roots which prevent the uptake of water and nutrients, reducing the potential yield of the crop.
Pythium species	Cold, wet soil conditions; known as water moulds, they enter untreated water supplies; water supplies for irrigation and hydroponics should be tested regularly.	Many vegetable crops in including cucurbits; brassicas; lettuce.	May kill seedlings, which die before they emerge or soon after emergence; plant collapse.
Sclerotinia rots (*S. sclerotiorum* and *S. minor*) – a range of common names are used	Windy, cool, humid weather; wet soil; survival structures known as sclerotia remain viable in soil for long periods (10-15 years).	Most vegetable crops.	Water-soaked rotting of stems, leaves, and sometimes fruit; followed by a fluffy, white and cottony fungal growth which contain hard black pebble-like sclerotia.
Sclerotium rots (*Sclerotium rolfsii* and *S. cepivorum*)	*S. rolfsii* – Warm, moist conditions. *S. cepivorum* –Development is favoured by cool soil conditions (14-19?C) and low	*S. rolfsii* – Wide host range including: beans; beets; carrot; potato; tomato; capsicum;	*S. rolfsii* – Lower stem and root rots; coarse threads of white fungal growth surround the diseased areas; small brown fungal resting bodies. *S. cepivorum* – Yellowing and wilting; fluffy fungal growth containing black sclerotia

	moisture.	cucurbits. *S. cepivorum* – only affects onions, garlic and related Alliums (shallots; spring onions; leeks).	forms at the bases of bulbs.
Fusarium wilts and rots (Various Fusarium species including *F. solani* and *F. oxysporum*)	Warm to hot weather.	Wide host range including: brassicas; carrots; cucurbits;onions; spring onions; potato; tomato; herbs; peas; beans.	Causes severe root and crown rots or wilt diseases by attacking roots and basal stems; cucurbit fruit and potato tubers can be affected in storage.
Botrytis rots – for example Grey mould (*Botrytis cinerea*)	Cool, wet weather.	Celery; lettuce; beans; brassicas; cucumber; capsicum; tomato.	Softening of plant tissues in the presence of grey fungal growth.
Anthracnose (*Colletotrichum spp.* except for in lettuce – *Microdochium panattonianum*)	Cool, wet conditions.	Wide range of crops including: lettuce; celery; beans; cucurbits; tomato, capsicum; potato; globe artichoke.	Typical symptoms begin with sunken and water-soaked spots appearing on leaves, stems and/or fruit.
Rhizoctonia rots (*Rhizoctonia solani*) – range of common names, e.g. Bottom rot (lettuce) and Wire stem (Brassicas)	Warm, humid weather; can survive for long periods in the soil in the absence of a host plant.	Wide host range including: lettuce; potato; brassicas;beans; peas; beets; carrots; capsicum; tomato; cucurbits.	Range of symptoms depending on the crop being grown but can affect roots, leaves, stems, tubers and fruit; plants wilt and may collapse and die.
Damping-off (Pythium, Rhizoctonia, Phytophthora, Fusarium or Aphanomyces)	Occurs under cold, wet soil conditions; shore flies and fungus gnats can spread Pythium and Fusarium.	Many vegetable crops including: leafy vegetables;brassicas; carrots; beetroot; cucurbits, eggplant; tomato;coriander; spring onions; beans	Young seedlings have necrotic stems or roots; seedlings die or show a reduction in growth.
Cavity spot (Pythium sulcatum)	Growing carrots after carrots; acidic soil; not harvesting carrots as soon as they reach marketable size.	Carrots.	Cavity spots are small elliptical lesions often surrounded by a yellow halo.
Tuber diseases (Various species)		Potato and sweet potato.	Potato tubers may be infected with superficial skin diseases, such as common scabs, powdery scab, and *Rhizoctonia.* Sweetpotatoes may be infected by scurf.
Rusts (several species, e.g. *Puccinia sorghi* – sweet corn; *Uromyces appendiculatus*	Wind can spread spores great distances; favoured by low rainfall, 100% relative humidity and cool to mild temperatures.	Sweet corn; beans; onions; spring onions; beets; celery; silverbeet; endive.	Small, red or reddish-brown pustules that form on the underside of the leaves and sometimes on the pods as well; dusty reddish-brown spores released from pustules (may be black in cold weather).

– beans; *Puccinia allii* – spring onions).			
Black root rot (Different species on different vegetable crops)	Cool soil temperatures; high soil moisture.	Lettuce; beans; cucurbits.	Blackening of roots; stunted plants; plants may die.

Other fungal diseases include:

- Target spot – *Alternaria solani* (tomatoes)
- Aphanomyces root rot – *Aphanomyces euteiches pv. phaseoli* (beans)
- Aschochyta collar rot (peas)
- Gummy stem blight – *Didymella bryoniae* (cucurbits)
- Alternaria leaf spot – *Alternaria cucumerina* and *A. alternata* (cucurbits)
- Black leg – *Leptosphaeria maculans* (brassicas)[7,8]
- Ring spot – *Mycosphaerella brassicicola* (brassicas)
- Late blight – *Septoria apiicola* (celery)
- Cercospora leaf spot – *Cercospora beticola* (beets)
- Leaf blight – *Septoria petroelini* (parsley)
- Septoria spot – *Septoria lactucae* (lettuce)
- Leaf blight – *Stemphylium vesicarium* (spring onions)
- Leaf blight – *Alternaria dauci* (carrots).[9,10]

DISCUSSION

Fungi are spread primarily by spores, which are produced in abundance. The spores can be carried and disseminated by wind currents, water (splashing and rain), soil (dust), insects, birds, and the remains of plants that once were infected. Vegetative fungal cells that exist in dead plant material also can be transmitted when they come in contact with a susceptible host. The survival of vegetative cells of plant pathogenic fungi in nature depends on climatic conditions, particularly temperature and moisture. Vegetative cells can survive temperatures from −5 to 45 °C (23 to 113 °F); fungal spores are considerably more resistant. The germination of spores, however, is favoured by mild temperatures and high humidity.[11,12]

Control

Because many thousands of fungal species can infect a broad range of plants and because each fungal species has different characteristics, a variety of practices are available to control fungal diseases. The principal control measures include the use of disease-free seed and propagating stock, the destruction of all plant materials that may harbour pathogenic fungi, crop rotation, the development and use of resistant plant varieties, and the use of chemical and biological fungicides.[13]

Several fungal diseases are characterized in the table.

Some fungal diseases of plants				
disease	**causative agent**	**hosts**	**symptoms and signs**	**additional features**
late blight of potato	*Phytophthora infestans*	potato	water-soaked dark green to black or purplish lesions with pale green margins on lower leaves, white mildew at edge of lesions	responsible for Irish famine; caused starvation and death and mass migration of population
chestnut blight	*Endothia parasitica*	chestnut tree	yellowish to reddish brown patches appear on bark; lesions spread quickly and girdle twigs or limbs, which die	disease accidentally imported from Asia; first observed in New York in 1904 and rapidly spread across the United States, practically eliminating native American chestnuts

Some fungal diseases of plants				
Dutch elm disease	*Ceratocystis ulmi*	elm tree	leaves wilt, turn dull green to yellow or brown, and drop off; branches die	the causative fungus is believed to have entered Europe from Asia during World War I and was later transported to the United States (1930) on elm burl logs imported for furniture veneer; elm bark beetles spread the pathogen in the United States
black stem rust of wheat	*Puccinia graminis*	wheat; many grasses	on wheat, rust-coloured pustules with spores, chlorosis of surrounding tissue, followed by development of black teliospores; on barberry, chlorosis and hypertrophy of infected tissue, orange spore masses	disease occurs wherever wheat is grown; in 1935 it destroyed about 60 percent of the total hard red spring wheat crop in Minnesota and South Dakota; fungus has a complex life cycle, partly on wheat and partly on the barberry plant; eradication of the barberry plant is an important control measure
coffee rust	*Hemileia vastatrix*	coffee	orange-yellow powdery spots on lower side of leaves; centres turn brown and leaves fall	most destructive disease of coffee; has caused devastating losses in all coffee-producing countries
white-pine blister rust	*Cronartium ribicola*	white pine tree	small, discoloured, spindle-shaped cankers surrounded by narrow band of yellow-orange bark; blisters exude secretion followed by bright orange pustules	one of the most important forest diseases in the United States; currant is the alternate host, and its eradication is an important control measure
corn smut	*Ustilago maydis*	corn	minute galls form on young corn seedlings; on older plants, large galls are produced on the silk of ears and on tassels, leaves, and stalks	occurs wherever corn is grown; may cause serious crop damage
loose smut	*Ustilago nuda*	barley, oats, wheat	infected heads are covered with masses of olive-green spores	worldwide occurrence; destroys kernels of the infected plant
downy mildew	many species of the family Peronosporaceae	many types of plants: grapes, grasses, vegetables, and others	yellow irregular spots appear on upper leaf surface; downy fungus growth appears on underside; leaves die	one of the first plant diseases controlled by a fungicide—i.e., Bordeaux mixture, a mixture of lime and copper sulfate used on grapes
powdery mildew	many species of the family Erysiphaceae	many types of plants: grasses, vegetables, shrubs, and trees	spots of powdery mildew growth that enlarge to cover leaves or other plant organs	one of the most common and widely spread plant diseases
apple scab	*Venturia inaequalis*	apple	small olive-coloured areas appear on young leaves, later turn black, and may coalesce; black circular spots appear on fruit	occurs almost everywhere apples are grown; infection reduces fruit size and quality
black spot of rose	*Diplocarpon rosae*	rose	large circular black lesions on leaves; leaves turn yellow and fall off	classified as an anthracnose, which affects leaves, stems, and fruits of many plants
anthracnose of grape	*Elsinae ampelina*	grape	(as above)	(as above)

Some fungal diseases of plants				
nectria canker	*Nectria galligena*	apple and pear and many hardwood forest trees	initially small circular brown areas that enlarge and become depressed with raised edges; callus tissue produced around canker	one of the most important diseases of pear, apple, and hardwood forest trees
black knot of plum and cherry	*Plowrightia morbosum*	plum and cherry	small black knotty swellings on twigs and branches	occurs primarily in the eastern half of the United States and New Zealand
brown rot	*Monilinia fructicola*	stone fruits	brown spots on blossoms; twigs develop small sunken brown cankers; fruit develops brown spots that spread rapidly	worldwide occurrence; can cause heavy losses both in orchards and in shipment
soft rot	*Rhizopus* s pecies	flowers, fruits, and vegetables with fleshy organs	tissues become soft with water-soaked appearance that often spreads rapidly, followed by development of fuzzy gray mycelium and black spores	infection develops most rapidly on ripe fruits with favourable conditions (moderate temperature and high humidity)
fusarium wilt of tomato	*Fusarium oxysporum*	tomatoes	leaves are bent down, growth is stunted, plant dies; dark streaks appear in vascular tissue	one of the most destructive diseases of tomato; entire fields can be destroyed
wilts of vegetables, flowers, and some trees	*Verticillium* species	cotton, potato, tomato, alfalfa, shade trees, and others	similar to fusarium wilts; develops primarily in seedlings that die shortly after infection; older plants also are attacked	worldwide distribution; the fungus infects hundreds of species of plants

CONCLUSION

Fungal plant pathogens can cause enormous losses in yield and quality of field crops, fruits, and other edible plant material, and this becomes increasingly a more important issue to human health and the global economy in this century, with increasing human populations and climate change threats to arable land.[14,15] Deciphering fungal pathogenesis not only allows us to better understand how fungal pathogens infect host plants but also provides valuable information for the control of plant diseases, including new strategies to prevent, delay, or inhibit fungal development. This special issue summarizes recent novel findings on plant fungal pathogenesis.[16,17]

Pathogenic fungi differ greatly in their life styles. Some are necrotrophic, while others are hemibiotrophic, biotrophic, or obligately biotrophic. Despite the obvious differences in life styles, fungal pathogens are known to use well-conserved proteins in infection processes. The conserved proteins are therefore potential targets for controlling these fungal diseases. Researchers focused on receptor for activated C kinase 1 (Rack1), a conserved protein involved in various biological processes in eukaryotes.[18,19] They reviewed functions of Rack1 proteins in model and pathogenic fungi. Rack1 proteins are involved in vegetative growth, conidiation, mating, toxin biosynthesis, and stress responses via different pathways including cAMP/PKA and MAPK pathways in different fungi, illustrating how Rack1 proteins are involved in fungal pathogenesis.

In order to infect, pathogenic fungi can develop specialized infection structures, such as appressoria to penetrate host cells. During this process, the peroxisomes play key roles to facilitate full functions of virulence proteins. X.-L. Researchers focused on roles of the peroxisomes in the rice blast fungus *Magnaporthe oryzae*. They described molecular mechanisms underlying how the peroxisomes function related to life cycles and metabolic processes. And also, they provided an overview of the relationship between peroxisomes and pathogenicity. This article will be valuable for researchers interested in understanding how the

peroxisomes serve as a platform to orchestrate plant host invasion by plant filamentous fungi.[20]

The hemibiotrophic fungus *Colletotrichum higginsianum* is the causal agent of anthracnose diseases on a wide range of cruciferous plants (Brassicaceae), including the model plant *Arabidopsis thaliana.* Also, the *C. higginsianum-A. thaliana* pathosystem is now considered to be an important model for studying fungal pathogenicity, in which both hosts can be efficiently genetically manipulated. The conserved pathogenic factors in various fungal pathogens that have been the subject of much study might also be considered targets for pesticide design. As a pleiotropic regulator of morphogenesis and plant infection, Ste7 MEK possesses highly conserved roles in phytopathogens. It was reported that the *C. higginsianum* gene *ChSTE7* is involved in regulation of vegetative growth, appressorial formation, and invasive growth in host tissues. This is an important and conserved virulence factor affecting infection of *C. higginsianum* on cruciferous plants.

Covalent histone modifications, such as methylation and acetylation, provide key epigenetic information in transcriptional regulation and chromatin structure organization for functional responses. Histone methylation provides an excellent epigenetic mechanism for stable transfer of gene expression profiles to progeny cells. In pathogenic fungi, the SET domain-containing proteins play essential roles in fungal growth and development. Scientists demonstrated that MoKMT2H, an Ash1-like histone modification protein, played important roles in conidial germination and pathogenesis in *M. oryzae*. They found that the Δ*Mokmt2h* null mutants are not defective in genome-wide histone methyltransferase modification, vegetative hyphal growth, conidial morphology, conidiation, or disease lesion formation on rice leaves. However, the *MoKMT2H* deletion mutants showed delayed conidial germination and attenuated virulence. Their results suggested that *MoKMT2H* plays an important role in conidial germination in the rice blast fungus.

The defense mechanisms of wheat against *Puccinia striiformis* f. sp. *tritici* (*Pst*) infection are complex, and activation of defense responses is critical in order to prevent the spread of pathogens. The plant cytoskeleton, including microtubules and microfilaments, is a highly dynamic subcellular structure that is associated with plant defense responses. J. Wang et al. focused on the function of microtubule polymerization in wheat against the stripe rust fungus *Pst* CYR23. They detected the frequency of hypersensitive cell deaths and H_2O_2 accumulations in leaves treated with microtubule inhibitor oryzalin before inoculation with strain CYR23. Depolymerization of microtubules reduced the resistance of plants via hypersensitive responses and led to decreased H_2O_2 accumulation, suggesting that microtubules play roles in resistance against the stripe rust fungus in wheat.[21]

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