Chapter 4

Plant Pathogens

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Additional information is available at the end of the chapter

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Abstract

Plants cover the most area of the earth's living environment as trees, grasses, flowers, and so on. Plants play different important roles in the environment such as ecosystem balance and food supplement for animals and humans. Moreover, wild or cultivated plants are considered the powerful biofertilizers for the soil, where the plant debris after death and degradation provides the soil with sufficient organic matters. Accordingly, plant care is a great duty and hard mission, which must be constantly improved. The study of plant pathogens belongs to the branch of biology known as plant pathology. The latter is also concerned to overcome the plant diseases arising from the biotic and/or abiotic origin. Biotic (infectious) diseases are developed owing to microbial infection, while abiotic (noninfectious) diseases are developed due to environmental factors. In this chapter, we are concerned with plant pathogens or phytopathogenic microbes such as bacteria, viruses, fungi, mollicutes, and so on.

Keywords: phytopathogens, biotic diseases, abiotic diseases, parasitism, pathogenicity

1. Introduction

The plant pathogens especially microbes will be the main subject of this chapter. The science, which is concerned with the study of plant diseases and their causes, is known as plant pathology. Therefore, all scientists concerned with this science constantly attempt to treat the diseased plants via various methods. This approach of scientific research is very important owing to the economic and hygienic yield for humans and animals. The phytopathogens are two types: biotic factors, which include all microbes and parasitic plants, and abiotic factors, which include all environmental factors. Essentially, the plant pathology is correlated with other sciences such as entomology, bacteriology, mycology, virology, and weed science due to

deleterious effects of insects, bacteria, fungi, viruses/viroids, and weeds on plants, respectively. The first step of plant disease treatment is observation of definite and clear symptoms on the plants. These symptoms give an initial indication for the type and cause of plant disease, which may end with the death [1]. The modern approach of plant disease control depends on biological control agents such as the production of antimicrobial agents and the production of genetic-improved strains of plants, which are more resistant to plant diseases. This approach is more favorable because it is friendlier with the environment and healthier for humans and animals [2]. The infected part of the plant gives an indication of the type of plant disease, such as infected root which is usually correlated with root-rot disease [3]. The plant diseases can be classified according to several parameters: disease symptoms, infected organ, infected plant type, and the type of phytopathogen. The latter is considered the more useful criterion used for plant disease classification, because it easily determines the disease cause, potential disease complications, and possible control methods [4]. According to this criterion, plant diseases are classified into two types: infectious (biotic) diseases, which are caused by eukaryotes, prokaryotes, parasitic higher plants, viruses/viroids, nematodes, and protozoa, and noninfectious (abiotic) diseases, which are caused by different extreme environmental conditions [5].

2. Basic procedures in the diagnosis of plant diseases

The plant disease diagnosis depends on the exact determination of the disease cause. Generally, there are two plant disease causes: the pathogens and/or environmental factors. The former leads to infectious diseases, while the latter leads to noninfectious diseases [6].

2.1. Infectious diseases

There are wide range of phytopathogens which cause infectious plant diseases such as fungi, bacteria, viruses, viroids, mollicutes, parasitic higher plants, and protozoa. The infectious disease means the ability of phytopathogen to transfer from the infected plant to another healthy one and causes the same disease and the same symptoms. The most phytopathogens can inhabit the internal environment of plants; however, some others can live on the plant surface such as some fungi, bacteria, and parasitic higher plants [7].

2.1.1. Diseases caused by parasitic higher plants

Some plant diseases are developed due to growing certain plants attached on or in other plants, where they take all required nutrients without benefit sharing; these plants are called parasitic higher plants. This abnormal relationship leads to weakness of healthy or host plant. The parasitic higher plants are usually found attached with the surface of the host plant, such as dodder, mistletoe, witchweed, and broomrape [8].

2.1.2. Diseases caused by nematodes

The nematodes are one of most common phytopathogens which have definite symptoms. These symptoms only appeared in the infected site. The nematode infections in or on plants

are widely distributed especially in proper environments such as moderate temperature and high humidity [9].

2.1.3. Diseases caused by fungi

Interestingly, there are two main types of fungi appearing on plants: pathogenic and saprophytic. The pathogenic fungi live in or on plant tissues and cause serious complications for the vital physiological functions of plants, while saprophytic ones live in or on dead tissues. Accordingly, the diagnosis of plant disease must be exactly carried out. The exact diagnosis and determination of fungi take place by microscopical examination to identify the mycelial morphological characteristics, whatever fruiting structures and spores. After complete identification for the fungus and the symptoms of plant disease, the latter should be compared with that reported in the reference. This study will exactly determine whether the fungus is a pathogen or a saprophyte. Although microscopical examination is an essential and effective method for fungal identification, it only sometimes cannot lead to exact identification due to the absence of fungal fruiting structures and spores on infected plant tissue. Therefore, an alternative method must be used, such as using selective media for isolation, identification, or promotion of sporulation. On the other hand, some fungi need to be incubated under certain temperature, aeration, or light conditions to produce spores [10].

2.1.4. Diseases caused by bacteria and mollicutes

The appearance of bacterial growth in or on plant tissues means that bacterial plant disease may be present, because saprophytes may be present. Therefore, accurate bacterial identification must be carried out by using microscopical examination and physiological parameter determination. The selective media are essentially used in the bacterial identification to determine the bacterial genus and species in some cases. Moreover, the confirmatory test of bacterial pathogenicity may be carried out by inoculation of single pure bacterial colony in the healthy plant, reproducing the same symptoms that appeared on the infected one. Moreover, immunodiagnostic techniques or serodiagnostic assays can be used, such as agglutination and precipitation, fluorescent antibody staining, and enzyme-linked immunosorbent assay (ELISA). There are several advantages for these techniques such as quite sensitivity, fairly specificity, rapid, easy to perform, and it is expected that standardized, reliable antisera will be available soon. Furthermore, there are recent methods used for bacterial identification, which depend on the automated analysis of bacterial fatty acid profile. The molecular biological techniques are also widely used [11]. There are uncommon microorganisms called mollicutes. These microorganisms are very small where they must be examined by an electron microscope. Mollicutes have polymorphism and lack cell wall–like mycoplasma. These microorganisms habit the young phloem cells as a convenient host, and cause severe plant diseases such as plant stunting, yellowing or reddening of leaves, proliferation of shoots and roots, production of abnormal flowers, and eventual decline and death of the plant. Mollicutes cannot be cultured on nutrient media except for the genus *Spiroplasma*. Mollicutes can be diagnosed by several parameters, such as symptoms determination, grafting, transformation, microscopical examination, susceptibility to tetracyclines, and so on [12].

2.1.5. Diseases caused by viruses and viroids

There are distinctive types of plant diseases caused by viruses/viroids. These diseases have definite and clear symptoms, which easily support disease diagnosis and are considered main advantage. Apart from this advantage, some recent techniques are widely used for disease diagnosis and virus identification, such as virus transmission tests to specific host plants by sap inoculation, grafting, certain insect, nematode, fungus, and mite vectors. Moreover, serodiagnostic tests are used for this purpose such as enzyme-linked immunosorbent assays, gel diffusion tests, micro-precipitin tests, and fluorescent antibody staining. The electron microscopy techniques as negative staining of virus particles in leaf dip or purified preparations are also used, as well as immune-specific electron microscopy. On the other hand, there are more accurate techniques used for disease diagnosis and virus/viroid identification, such as electrophoretic tests and hybridization of commercially available radioactive DNA complementary to a certain virus DNA or RNA, or viroid RNA, with the DNA or RNA present in plant sap and attached to a membrane filter (immunoblot) [13].

2.1.6. Diseases caused by more than one pathogen

Sometimes, some plants are exposed to coinfection by two or more pathogens, which lead to the same or different disease symptoms. Therefore, the differentiation and identification of these pathogens are very essential to exactly determine the disease cause. The differentiation and subsequently identification are carried out by all techniques that are mentioned above [14].

3. Noninfectious diseases

Occasionally, some plant diseases have abiotic origin such as environmental factors; these diseases are called noninfectious diseases. Abiotic environmental factors have deleterious effects on plants under extreme conditions, because they can negatively effect on the vital physiological functions and may lead to death, for example, the presence of considerable amounts of toxics in the soil or in the air, deficiency of water, oxygen, or minerals, and extreme conditions for temperature, humidity, oxygen, CO, or light [7].

4. Parasitism and pathogenicity

The term parasitism called on the state in which an organism (parasite) lives on or in another one (host) to obtain its required nutrition. Usually, the parasitism is correlated with pathogenicity, which means the ability of an organism to cause a disease. However, the parasitism in some cases leads to a benefit relationship called symbiosis, in which both plant and organism alternate the benefits, such as bacterial nodules in the roots of legume plants and the mycorrhizal infection of feeder roots of most flowering plants. In the case of parasitism-pathogenicity relationship, the plant is diseased with the appearance of different symptoms such as increased

respiration, disintegration or collapse of cells, wilting, abscission, abnormal cell division and enlargement, and degeneration of specific components such as chlorophyll [15]. The most common plant pathogens are fungi, bacteria, mollicutes, parasitic higher plants, parasitic green algae, nematodes, protozoa, viruses, and viroids. These parasites cause serious plant diseases, because they have the ability to penetrate the plant tissues to feed and proliferate in it, and withstand the conditions in which the host lives. These pathogens are also called obligate parasites because they can only live in their living hosts. On the other hand, there are certain pathogens such as most fungi and bacteria can live on either living or dead hosts and on various nutrient media, so they are called nonobligatory parasites. Some nonobligatory parasites can grow saprophytically on dead organic matter, and therefore called semi-biotrophs/facultative saprophytes [16]. There is a type of a life called facultative parasitism, in which an organism grows saprophytically (necrotrophs); however, under certain conditions, they attack living plants and cause a disease; these parasites are called facultative parasites. The type or degree of parasitism does not affect the disease severity. For instance, many diseases caused by weakly parasitic pathogens are much more damaging to a plant than others caused even by obligate parasites. Lysozymes are a main mechanism of most nonobligatory parasites by which they can degrade the plant cell wall and subsequently cause invasion and infection [17].

5. Host range of pathogens

Phytopathogens differ among each other with respect to the plant type, the location of infection, and the age of the organ or tissue (location of infection). The specificity of plant pathogens has various degrees; some pathogens have only one target species of plant, while other pathogens can attack only one genus of plants, and eventually some others have a wide range of hosts, belonging to many families of higher plants. As mentioned above, phytopathogens differ among each other with respect to the location of infection; some of them grow on roots, stems, leaves, fruits or vegetables, and phloem or xylem. Some phytopathogens can only infect the seedlings or the young parts of plants, while the others can only infect the mature tissues [18].

6. Development of disease in plant

The plant disease means the occurrence of physiological disorder(s) due to biotic agents such as microbial infection and/or abiotic agents such as extreme environmental factors. In order for the plant disease to occur, an interaction must happen between two components: the plant and disease cause, which leads to physiological disorders. The disease cause is either biotic agent or abiotic agent as mentioned above. Interestingly, the biotic agents lead to infectious diseases, which develop under suitable environmental conditions. Therefore, the infectious diseases (occurred by pathogens) are not developed under extreme environmental conditions. This means it was impossible to get infectious and noninfectious plant diseases at the same

time. The abiotic agents (environmental factors) play an important and vital role in the disease development and severity or disease resistance. This matter depends mainly on different factors: the plant family, the plant age, plant genetic type, pathogen virulence race, pathogen inoculum size, and pathogen dormant state. Therefore, we can imagine the plant disease as a triangle, which is called "disease triangle." The three sides of this triangle are the plant, microorganisms, and the environmental factors. The length of each side is proportional to the sum of the characteristics of the other two sides. For example, if the plant is resistant, the host side and the amount of disease would be small or zero, whereas if the plant is susceptible, the host side would be long and the potential amount of disease could be great [19].

6.1. Disease cycle

The disease cycle is a series of definite events, which lead to the disease development and pathogen propagation. These events include inoculation, prepenetration, penetration, infection, colonization (invasion), and growth and reproduction of the pathogen [20].

6.1.1. Inoculation

Inoculation is the pathogen or any part of the pathogen that contacts with the plant at certain site to initiate the infection process, such as spores, sclerotia, or fragments of mycelium of fungi may be fungal inoculum. In some cases, the inoculum is represented as an intact cell as in bacteria, mollicutes, protozoa, viruses, and viroids. There are two types of inoculum: primary and secondary inoculum, which in turn cause primary and secondary infection. The primary inoculum lives dormant in the winter or summer and causes the original infections in the spring or in the autumn. The secondary inoculum is that produced from primary infections. The primary inoculum is more abundant than secondary inoculum and closer to the crop, and caused more severe diseases and the losses that result. The inoculum has two sources: inside and outside sources. The inside source in which the inoculum is produced on the plant, plant debris, or on the soil, such as fungal and bacterial inocula of perennial plants, is produced on the branches, trunks, or roots of the plants. The outside source of inoculum is in which the inoculum comes into the field with the seed, transplants, tubers, or other propagative organs or it may come from sources outside the field. In some cases, the inoculum is produced on the plant surface as in fungi, bacteria, parasitic higher plants, and nematodes, which either produce their inoculum on the surface of infected plants or their inoculum reaches the plant surface when the infected tissue breaks down. However, the inoculum may be produced within the plant as in viruses, viroids, mollicutes, fastidious bacteria, and protozoa. Interestingly, there is an expression called inoculum landing or inoculum arrival, which means incoming of the inoculum to the host plants passively by wind, water, and insects [21].

6.1.2. Prepenetration

6.1.2.1. Attachment of pathogen to host

Some pathogens directly penetrate the plant tissues by their vectors and then are surrounded by cytoplasm, cell membrane, or cell wall of plant cell, such as mollicutes, fastidious bacteria,

protozoa, and most viruses. In other cases, the pathogen firstly makes contact with the external surface of the plant, and then penetration process takes place, such as fungi, bacteria, and parasitic higher plants. The adhesion of the pathogen with plant surface is carried out by mucilaginous substances found on the pathogen surface or at its tip. These substances are composed of mixture of water-insoluble polysaccharides, glycoproteins, lipids, and fibrillary materials, which, when moistened, become sticky and help the pathogen adhere to the plant. In some fungi as powdery mildew, adhesion is carried out by the release of cutinase enzyme from the spore, which makes the plant and spore areas of attachment more hydrophilic and cements the spore to the plant surface [22].

6.1.2.2. Spore germination

Spore germination process initiates by growth stimulation, which takes place with the availability of proper environmental conditions. Once the stimulation has been received, the spore starts to utilize the stored food, such as lipids, polyoles, and carbohydrates to build germ tube as abridge with cell membrane and cell wall of the plant. When appropriate physical and chemical signals, such as surface hardness, hydrophobicity, surface topography, and plant signals, are present, germ tube extension and differentiation take place [23].

6.1.2.3. Appressorium formation and maturation

Appressorium is a specialized cell typical to many fungal plant pathogens that is used to infect the plant host. Once appressoria are formed, they adhere tightly to the leaf surface and then penetrate the plant cell wall via lysozyme secretion [24].

6.1.2.4. Recognition between host and pathogen

When a pathogen comes in contact with a host cell, the plant triggers a signal that either allows or retards the pathogen growth and development of disease. This signal is a biochemical reaction, which acts as a receptor to a pathogen contact. The pathogen propagation depends on the components of the plant cell, such as fatty acids galacturonan, phenolic compounds, strigol, amino acids, and sugars [25].

6.1.2.5. Spores and seed germination

The availability and ability of host infection are increased by vegetative pathogen. The infection by fungal spores or parasitic higher plant seeds is carried out after germination has achieved. Fungal spores' germination is carried out by releasing either a mycelium or a germ tube that grows into the plant cell and cause infection [25].

6.1.2.6. Growth of nematodes

The growth of nematodes starts with hatching of eggs, which essentially requires convenient environmental conditions such as temperature and moisture. After hatching of the eggs, the larvae penetrate the plant cell and grow to form the adults. After maturation, the adults of

nematodes closely adhere with plant roots due to some factors, such as carbon dioxide and amino acids [9].

6.1.3. Penetration

Phytopathogens penetrate plant surfaces either through natural openings such as fungi and nematodes or through wounds in cell wall such as bacteria, viruses, viroids, mollicutes, fastidious bacteria, and protozoa. Penetration and infection are not usually correlated together, because some penetrated plants are resistant to phytopathogens [26].

6.1.4. Infection

The intimate contact of phytopathogen with its host is called infection process. The infection process is either successful or unsuccessful depending on the type of host, whether susceptible or resistant, respectively. Successful infection results in the appearance of symptoms, such as discoloration, necrosis, dwarfism, and so on of the host. While unsuccessful (latent) infection does not lead to any observations for the symptoms. As well known, the symptoms start to appear after the incubation period of the pathogen has been finished. The symptoms either are stable or may be changed until death [27].

6.1.5. Invasion

The phytopathogens can invade the plant tissues by producing mycelia which grow between the cuticle and epidermis, such as pathogenic fungi of an apple. Nevertheless, other phytopathogens such as those causing powdery mildews produce mycelia which grow on the plant surface, and then extend to form a structure called haustoria, which in turn extend into the epidermal cells. Therefore, plant pathogenic fungi can invade their host either by intracellular mycelia, which directly grow through the cells, or by intercellular mycelia, which grow between the cells. On the other hand, plant pathogenic bacteria invade the plant tissues via intercellular way, and cause vascular wilts. Although nematodes can invade the plant tissues intercellulary or intracellularly, they usually feed on the epidermal cells by piercing. Other phytopathogens such as viruses, viroids, mollicutes, fastidious bacteria, and protozoa can intracellularly invade the plant tissues [28].

6.1.6. Growth and reproduction of the pathogen

Most phytopathogens especially fungi and parasitic higher plants invade and infect plant tissues through the point of inoculation. Therefore, these pathogens can easily grow and spread within the plant tissues until a certain limit or death occurs. For example, fungi can invade and infect the plant tissue to cause vascular wilts. This invasion is carried out by releasing spores within the vessels [29].

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