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Review Article

Biology, Ecology, Symptoms and Management of Downy and Powdery Mildew Diseases: A Review

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Abstract

Downy mildew and powdery mildew are fungal diseases that cause diseases in plants. They are a major limiting factor for the production and productivity of crops and they are caused extensive quantitative as well as qualitative damage to the crops. These plant pathogens damage crop quality and yield worldwide. They cause a variety of symptoms on the affected plant parts and cause severe infections. The severity of downy and powdery mildew diseases varies and the variations depend on the environmental conditions. During favorable environmental conditions, they cause serious yield reduction. To minimize the losses caused by these fungal pathogens it is important to understand the pathogen biology, ecology, symptoms, damage, and differences between the two fungal pathogens that is important for identification and successful management methods. Hence, the objective of this review is to summarize current knowledge on the general biology, ecology, symptoms, damage, and control of downy mildew and powdery mildew of fungal diseases. Downy mildew and powdery mildew fungi cause significant diseases in a variety of economically important crops. These diseases often cause rapid and severe losses of crop yields. To reduce the losses caused by downy mildew and powdery mildew diseases, timely application of cultural, chemical, biological, host plant resistance, and integrated disease management methods are essential. Therefore timely application of management methods for mildew diseases is crucial for effective control. Specifically, integrated disease management serves as the most effective strategy to minimize the damage caused by these diseases, ultimately enhancing both the quantity and quality of crops globally.

Keywords

Biology, Damage, Disease, Downy Mildew, Fungi, Management Methods, Powdery Mildew, Symptoms

1. Introduction

Fungi are eukaryotic, tiny, usually microscopic, branching, generally filamentous, spore-bearing organisms that lack chlorophyll. Above 19,000 fungal species are known to cause disease in crop plants globally [1]. All plants are attacked by some type of fungus, and each parasitic fungus can attack one or more types of plant species. Fungi can stay inactive yet alive on both living and deceased plant matter until the circumstances become favorable for their growth and multiplication. Certain fungi may develop inside host plant tissues. Fungal spores are readily dispersed by wind, water, soil, insects, and other invertebrates. In this way, they may infest an entire crop [2].

Fungi are responsible for the majority of plant diseases. They cause diseases in plants are a diverse group [3]. Patho-

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genic fungi that cause plant diseases such as rust, anthracnose, leaf spot, blight, wilt, scab, gall, canker, dieback, damping-off, root rot, and mildew [1]. Downy and powdery mildew are fungal diseases that cause diseases in plants and they are major causes for yield losses and reduced crop quality and quantity worldwide.

Downy mildew is a fungal pathogen that causes diseases in plants to belong to the family *Peronoporaceae* in the class *Oomycetes*. The major genera causing downy mildew include *Peronospora*, *Plasmopara*, *Bremia*, *Pseudoperonospora*, *Sclerospora*, and *Sclerophthora* [4]. Downy mildew fungi are obligate parasites that primarily infect the leaves, branches, and fruits of susceptible hosts forming a 'downy bloom' consisting of sporangiophores and sporangia on the surface of infected plant parts. It affects important crops and causes severe losses in production globally. Downy mildew affects numerous plant species that are economically important crops [1]. Numerous species are severely damaged to the most significant crops such as pearl millet, corn, sorghum, sunflower, soybean, brassica, opium poppy, cucurbits, onion, grapes, and flowers, like roses [4].

Powdery mildew diseases of various crops or other plants are caused by many species of fungi of the family *Erysiphaceae* [3] which are obligate, ascomycete pathogens [5] that have been reported to infect over 10,000 flowering plant species worldwide, including several economically important plants [6, 7]. Thus, powdery mildew is considered one of the most important plant pathogens [8]. This mildew is one of the most prevalent plant pathogens in the world with an estimated 873 species within 18 genera [9] and 5 tribes [5].

The name, powdery mildew is a term derived from the general observation that plant parts affected by the disease usually appear as if they have been dusted with fine white powder. This fine white powder is, in reality, a mass of abounds mycelia, conidiophores, and conidia of the fungus, which normally grows on the surface of the host. These mildew diseases are some of the world's most frequently encountered plant-pathogenic fungi [7]. It can be caused by many commonly occurring plant pathogenic fungi capable of infecting several plants. The disease is widespread and affects various plant species in different climatic zones [10]. This fungus causes significant diseases in different crops and a variety of species of fungi are involved depending on the plant affected [11].

Powdery mildew, which is a prevalent and harmful plant disease, can be found across various economically significant crops, affecting a wide range of plant species. Economically important crops, including wheat, barley, grapevines, apples, several vegetables, and many ornamentals, grown in the field and greenhouses are among the major targets of powdery mildew fungi [12, 7]. Powdery mildew diseases are widespread in fruit-growing regions worldwide, and when ideal conditions for disease progression are present, they can lead to significant reductions in crop yields. The disease is common in cereals and many species of grasses and is one of the most dangerous fungal diseases of wheat and barley, every year causing losses in yield volume and quality. It is less damaging to rye and oats, and until recently did not affect triticale [10].

Both downy and powdery mildew diseases are widely distributed as detrimental plant disease that occurs on different economically important crops. They can result in decreased growth, and flower and fruit quantity and quality of the crops. They continue to generate serious economic penalties for crop production. To reduce the losses caused by downy mildew and powdery mildew diseases, it is important to manage these mildew diseases. To develop an effective management method sound knowledge of pathogen biology, ecology, symptoms, and damage of downy mildew and powdery mildew of fungal diseases is essential. An understanding of the differences between these two fungal pathogens is also important for recognition and successful management methods. Therefore this review is to summarize current knowledge on the general biology, ecology, symptoms, damage, and control of the downy mildew and powdery mildew of fungal diseases, with a focus on sustainable control methods.

2. Downy Mildew Disease

2.1. Biology of Downy Mildew

Reproduction of downy mildew is usually both by sexual and asexual means. Most fungi produce reproductive structures known as spores. Spores can be sexual or asexual depending on the type of fungus and the stage of its life cycle. During the sexual stage, oospores are formed that are thick-walled and long-lived and allow the pathogens to survive the crop-free, adverse periods [13]. Oospores are thick-walled and so able to survive unfavorable conditions. They probably survive in or on rotting plant debris in the field. Oospores are the primary source of inoculum. Sexual reproduction leads to variation or genetic differences in the offspring which is an advantage for the survival of the species, especially under changing environmental conditions. The products of sexual reproduction are the oospores. Their formation is favored by factors causing normal senescence of host tissue. Consequently, they are plentiful in yellowing and dying leaves and senescing cotyledons and they are seldom in green tissue [14].

Asexual or vegetative reproduction in downy mildew is the production of genetically identical spores (sporangiospores), with no sexual processes. In downy mildews the asexual spores are produced on the tips of microscopic tree-like structures (sporangiophores). These structures emerge through the stomates on the undersurfaces of leaves, at night. In the early morning, they appear as a fluffy white mass on the undersurface of cotyledons and leave [14].

The asexual phase happens when the weather is favorable. Asexual reproduction is through the production of conidia or sporangia. Sporangia create zoospores which are the infecting propagules, while conidia germinate directly [4]. Several

pathogens, including *Perenosclerospora sorghi*, *Perenospora parasitica*, and *P. tabacina* generate conidia while others, like *S. graminicola* and *Pseudoperonospora cubensis* produce sporangia and zoospores. Conidia-producing pathogens are thought to be evolutionarily more advanced than those producing sporangia [15]. Asexual spores of the downy mildew pathogens are ephemeral, therefore rapid dispersal and infection are essential. Asexual spores are the major means of fungal spread. The higher the spore loads the higher the intensity of the infection. Wind speed, relative humidity, temperature, sunshine, and leaf wetness can influence the viability and dispersal of spores. Sporangia of *S. graminicola* remain viable for 2.5-6h depending on temperature, relative humidity, and wind speed [16], and under favorable conditions, they can be transported up to 3km by the wind. In sunflower downy mildew, rain immediately after sowing was crucial for disease initiation and spread [17].

2.2. Ecology of Downy Mildew

Almost all plant pathogenic fungi spend part of their lives on their host plants and part in the soil or plant debris on the soil. Some fungi are strictly biotrophs, i.e., they spend all of their lives on the host, and only the spores may land on the soil, where they die or remain inactive until they are again carried to a host on which they grow and multiply. All species of *Peronosporaceae* family are obligate parasites of higher plants and cause downy mildew diseases on most cultivated grain crops, vegetables, field crops, ornamentals, shrubs, and vines [3].

The survival and performance of most plant pathogenic fungi depend greatly on the prevailing conditions of temperature and moisture or the presence of water in their environment [3]. Temperature and humidity play key roles in the pathogen's development. Symptoms of the disease can develop under a range of temperature and relative humidity conditions for different downy mildews. During cool and wet conditions with high relative humidity of 85% or more, downy mildew outbreaks build up when germinating oospores form sporangiophores, which resemble clusters of grapes developing from the plant stomata. Prolonged leaf wetness promotes spore germination and the disease's dissemination, thus keeping plants dry reduces the spread of this disease. That is relative humidity is a critical element to initiate sporulation [18]. All *Peronoporaceae* need a wet surface for spore germination and infection, and high relative humidity for spore production. Thus rainfall and high relative humidity are critical weather factors for epidemics to develop. The downy mildew pathogens infecting maize, sorghum, and pearl millet have similar environmental requirements for asexual reproduction [4].

The downy mildew disease can survive on infected shoots, leaves, and cones. It often overwinters as intercellular mycelium in infected dormant buds and crowns. When dormancy breaks, shoots are already infected due to mycelium that overwinters in the crown, which causes it to disseminate into growing buds during the winter and early spring and result in primary basal spikes. However, infected crowns do not always produce basal spikes; occasionally, infected crowns produce both healthy shoots and infected basal spikes and contaminated crowns produce only healthy shoots [19].

2.3. Symptoms of Downy Mildew

The downy mildew fungus produces characteristic diseased shoots, called spikes. Spikes are stunted with short internodes, and look chlorotic with yellow-green, down-curling, or cupping leaves [19]. The leaves are frequently brittle and dry up starting at the base of the spike. Downy mildew disease causes localized leaf lesions to appear on the bottom of the leaves. These disease lesions are usually bounded by leaf veins that appear angular and water-soaked [20]. These lesions become necrotic and light to dark brown. Sporangia can form a mass at the underside of leaves or spikes and appear as a purplish gray or black growth. Infected flowers are dark brown, shriveled, and dry and may fall off the plant. Cones turn brown and hard and stop developing if infected early. Depending on the time of infection the cone can be completely dark brown or have only a few discolored bracts, giving a striped or variegated appearance [19].

Downy mildew disease produces irregular, yellowish, translucent sports on the upper part of the leaf surface. The affected leaves turn yellow, and brown as well as dry out. It shows premature defoliation, dwarfing of tender shoots, and brown, sunken lesions on the stem. Downy mildews produce a 'downy' mass of spores (sporulates) on the under leaf surface symptoms of flecking, speckling, and blotching appear on the upper leaf surfaces and heavily infected leaves may yellow, prematurely wither, and then die. It manifests as yellow-to-white patches on the upper surfaces of mature leaves. The fungus forms downy mycelial masses that appear after rain and heavy dew and then rapidly regress after sun exposure resumes [1]. Infected leaves turn brown and papery and may abscise despite adequate internal moisture. Downy mildew is cold tolerant and the pathogen resides in the plants and the soil. The spores are transmitted by insects, wind, rain, and gardening tools [21].

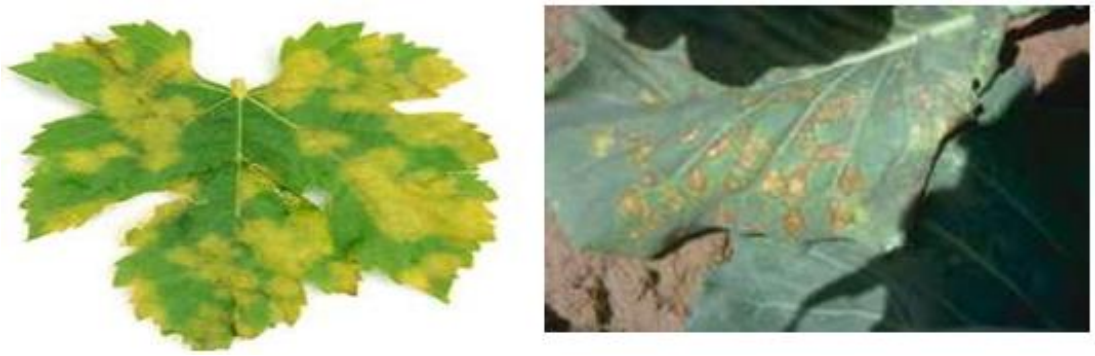

Figure 1. *Symptoms of downy mildew disease on leaves.*

2.4. Damage of Downy Mildew

Downy mildews are plant pathogens that damage crop yield and quality all around the world. The diseases occurring in different genera of host plants are caused by different genera or species of fungi. Many species of this disease are highly destructive to most important crops, such as pearl millet, sorghum, maize, sunflower, brassica, soybean, cucurbits, onion, grapes, and flowers, like roses [4]. This disease causes extremely significant problems in nursery seedlings, if not controlled timely. They are prevalent in cool wet months but can occur all year round. The diseases generally don't kill the plant; they make it look ill, uncared for, and therefore unsalable. The downy mildew diseases cause high economic losses in the production of ornamental and vegetable seedlings in nurseries. That is downy mildews are primarily foliage blights caused by obligate biotrophic plant parasites which result in considerable economic losses on numerous crops [22].

Downy mildews often cause rapid and severe losses of young crop plants still in the seedbed or the field. The pathogen infects young, tender green leaf, twig, and fruit tissues, resulting in substantial losses within a short period. They often destroy 40 to 90% of the young plants or young shoots in the field, causing heavy or total losses of crop yields in optimal humidity and temperature [3, 23]. The severity of loss depends on the prolonged presence of wet, cool weather during which the downy mildews sporulate profusely, cause numerous new infections, and spread into and rapidly kill young succulent tissues. In cool, wet weather downy mildews are often uncontrollable, checked only when the weather turns hot and dry. Since the discovery of systemic fungicides, our ability to control these diseases has improved considerably, although downy mildews are still very difficult to control [3].

2.5. Management of Downy Mildew

2.5.1. Cultural Control

Cultural methods for controlling downy mildew are largely aimed at sanitation and manipulation of the environment to the advantage of the host and the detriment of the pathogen. Since the pathogens survive in the form of oospores in the host tissues, removal, destruction, and burning of the infected plant debris along with weeds serve to reduce the primary inoculum. For the management of downy mildew diseases, clean, well-drained soils with a two-year crop rotation with a non-host crop have been suggested. Avoidance of monoculture and avoidance of growing the same variety in specific fields reduces the inoculum development and limits virulence selection in the pathogen population. To lessen the initial stage inoculum load and secondary spread of the disease, it has been suggested to practice crop sanitation, deep cultivation, over-planting and rouging of diseased plants, host nutrition, adjusting planting dates, crop rotation, and inter- and mixed cropping [4].

Removing the source of primary infection can significantly reduce the severity of the epidemic [24]. The achievement of sanitation practices depends on thoroughness and can help postpone an epidemic. In addition to pruning and stripping, other practices are critical to disease control, like avoiding excessive nitrogen fertilization, keeping all areas clean and weed-free, rogue out heavily infected seedlings as these provide a source of spores for subsequent infections, avoiding watering seedlings in the mornings, when spores are released and available for infection. Using overhead watering should also be avoided, as it increases leaf wetness. In cases where disease incidence is high, early harvest can be a means of reducing cone infestation [19].

2.5.2. Host Plant Resistance

Planting resistant cultivars is an important first step in preventing a serious outbreak of downy mildew fungal diseases [20]. Host plant resistance (HPR) is an important management method of downy mildews that is a practical and economic way to control the diseases. The use of resistant variety is considered as most economical and effective control measure for plant diseases. This is a novel technology embedded in seed, which does not incur any direct costs to farmers and doesn't require extra effort and understanding to utilize for disease management. The best and most sustainable means of plant protection is the breeding of resistant cultivars. The use of HPR requires an effective screening technique;

good sources of genetic resistance; a proper breeding method to efficiently incorporate the resistance; a sound strategy for cultivar deployment; and an effective monitoring system for pathogen virulence and resistance durability [4].

2.5.3. Biological Control

Plant extracts like garlic juice extract are reported to be toxic to *P. parasitica* on radish [25]. Treatment of opium poppy seeds with *Azotobactor* species reduced the downy mildew disease incidence and also the nitrogen requirement of the crop [26]. However, it requires further investigation to improve the effectiveness of the *Azotobactor*. The capacity of biological control agents for managing downy mildew diseases looks very limited as compared with seedling and root diseases. Biological products need to be applied as protectants to be effective in controlling powdery mildew *Bacillus subtilis* and *Trichoderma harzianum* [27].

2.5.4. Chemical Control

If the weather conditions are favorable for downy mildew, spraying chemicals to prevent the disease is key [19]. Chemical control of downy mildew is the most practical. Several non-systemic and systemic fungicides have been tried for the control of downy mildew in various crops [28]. Both pre-infection (protective) and post-infection (systemic or penetrant) fungicides are widely used for the control of downy mildew. Pre-infection chemicals are applied before, but as close as possible, to an infection event. The advent of metalaxyl (methyl *N*- (2, 6-dimethylphenyl)-*N*- (methoxyacetyl)-DL-alaninate), a systemic fungicide, provided a real breakthrough for the control of downy mildews. The fungicide is absorbed through the leaves, stems, and roots and inhibits protein synthesis in the fungus. It has a variety of formulations and can be used as a seed treatment or foliar spray. Fungicidal seed treatment followed by a foliar spray is a common practice to control downy mildews when deemed economical [4].

Consequently, the chemical control method remains the most efficient and cost-effective approach to safeguard crops from downy mildew disease under conditions favorable to disease development. Mancozeb is registered for downy mildew control on a variety of plants. Mancozeb appears to be most effective in combination with systemic fungicides. The most effective fungicides for the control of downy mildew have been copper-based products such as the Bordeaux mixture, some broad-spectrum protective fungicides, and several systemic fungicides. Despite the potential drawbacks of long-term copper accumulation in soils, which can lead to soil fertility decline and negative impacts on soil microbiota, copper-based fungicides, the oldest products in plant protection, continue to be utilized in viticulture [29, 30].

The applications of chemicals start before the flower and continue every 7-10 days or, depending on the frequency and duration of rainfall, at the time of the growing season. Disease prediction systems, based on the duration of leaf wetness, relative humidity, and temperature, are used to identify infection periods and to time fungicide applications [3].

2.5.5. Integrated Disease Management

Cultural, chemical, host plant resistance, and biological control are the components of integrated disease management (IDM). The cultural management method has been partially successful in most cases to reduce the primary inoculum. Metalaxyl is an effective fungicide for downy mildew; however, the development of metalaxyl-resistant strains in some downy mildew pathogens, such as *P. parasitica* [31] has limited its broad use. Biological management of downy mildew disease has so far been limited to experiments and it will need considerable research efforts to achieve any success. Host plant resistance offers the best opportunity to manage the downy mildews [4].

3. Powdery Mildew Disease

3.1. Biology of Powdery Mildew

Powdery mildew reproduces by both sexual and asexual reproduction methods. Conidia are produced by asexual spores, and cleistothecia (ascocarps or fruiting bodies) which contain ascospores are produced by the sexual stages. The number of asci (a sac-like cell that contains ascospores) in each cleistothecium and the type of cleistothecial appendages identify the genera of this group of fungi. The ascocarp is vital to the survival of fungi and can serve as an overwintering structure. The asexual, or conidial, phase of the infection aids in to dissemination of the disease and intensifies its effects. The majority of fungi produce reproductive structures called spores. Depending on the type of fungus and the stage of its life cycle, spores can be sexual or asexual. When spores germinate, they produce thread-like structures known as hypha. An aggregate of hyphal strands known as mycelium grows on the surface of the host tissue but does not pierce the epidermal tissue. The mycelia produce appressoria (organs that form from a hypha for attachment to a host) which attach to the surface of the host. From the appressorium, haustorium (a hyphal branch) is produced which penetrates the host cells of the plant to get nutrients. In general, fungi reproduce through both asexual and sexual methods [3].

3.2. Ecology of Powdery Mildew

The mildew fungus overwinters as conidia or mycelium in diseased buds, or on leaves, stems, and other plant parts in geographical areas with mild winters. The fungus continues its growth the following spring and is first noticed in the new growth. In areas with severe winters, the fungus overwinters as cleistothecia on plant debris. In the spring, cleistothecia produce ascospores, which, like conidia, are blown to healthy tissue and cause new infections [32]. The climatic conditions

throughout the growing season have an impact on the growth and development of powdery mildew. Although free moisture is required for the release of ascospores from cleistothecia, powdery mildew flourishes under dry conditions with moderate temperatures. Mild weather results in increased powdery mildew growth. High temperatures can harm the fungus. It can be destroyed completely when air temperatures rise above 32 ℃ for 24 hours or more [33]. Moderate temperatures and shady conditions are generally favorable for powdery mildew development [34]. Disease severity is usually higher in the late summer seasons [35].

Powdery mildews are severe in warm, arid climates. This is due to the fungus does not require the presence of water on the leaf surface for infection to happen. In cool or warm humid areas powdery mildew diseases are prevalent and can lead to serious disease. They are most commonly found, and considerably more severe, in warm dry climates. This occurs because their spores can be released, germinate, and cause infection even in the absence of a water film on the plant surface, as long as the relative humidity in the air is fairly high (80-99%). Atmospheric water in the form of humidity is essential and conducive to spore germination. Unlike most plant pathogenic fungi, species of powdery mildew can germinate and infect the host tissue without free water; however, the humidity requirements for germination vary. The presence of free water can kill the spores of this fungus and limit the growth of the mycelium. Once infection has begun, the mycelium continues to spread on the plant surface regardless of the moisture conditions in the atmosphere [36].

3.3. Symptoms of Powdery Mildew

The first symptoms of powdery mildew in cereals and grasses develop on winter cereals in late autumn or early spring. The disease is most usually observed above the leaves and it also affects the underside of leaves, young stems, fruits, buds, and flowers. Infected leaves may become distorted, turn yellow with small green spots, and drop prematurely. Diseased buds may fail to open [37]. An indication of established powdery mildew is a white to grayish powdery webby coating on the surface of leaves, stems, buds, or fruit. The coating consists of superficial, interwoven threads of fungus and chains of spores. Usually, powdery mildew diseases are characterized by the appearance of spots or patches of white to grayish growth on young plant tissues [36].

If the powdery growth is removed, a brown to black lesion is usually found on the plant surface. This may be all that is evident if growth conditions for the fungus are unfavorable. There are numerous kinds of powdery mildew fungi exist; all of which induce similar symptoms on various parts of plants. Powdery mildew diseases are characterized by spots of white to grayish, talcum-powder-like growth. Small, pinhead-sized, spherical fruiting structures that are white at first, then yellow-brown, and finally black may occur singly or in a group in the host tissue [37]. The individual spots can enlarge, coalesce, and completely cover the infected organs of the host within a short period. On older leaves or plant parts, powdery mildew can also be severe. Leaves that are heavily infected with powdery mildew may become chlorotic and senesce early [32].

Figure 2. *Symptoms of powdery mildew disease.*

Typical symptoms can include stunting and distortion of leaves, buds, growing tips, and fruit; death of invaded tissue; yellowing of leaves; premature leaf fall, blemished or aborted flowers, and a general decline in plant growth and vigor. Powdery mildew diseases produce a 'powdery' mass of white spores on the upper part of the leaf surface or the surface of affected plant parts. Leaves may eventually be yellow but they tend to persist on the plant. The pathogen has a preference for infecting younger leaves with high moisture content. Mature leaves are less commonly infected [38].

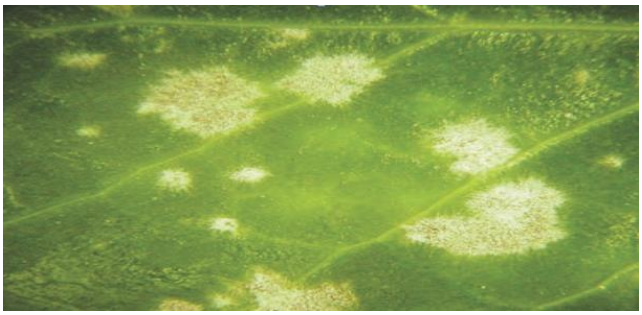

Figure 3. *Fungal growth of powdery mildew on leaf.*

3.4. Damage of Powdery Mildew

Powdery mildew disease is one of the most common widespread and simply recognized plant diseases in the world. They affect almost all types of plants: cereals and grasses, vegetables, fruit trees, ornamentals, weeds, shrubs, and broad-leaved shade and forest trees. Powdery mildew is common, widespread, and very present among crop plants and ornamentals. The total losses in plant growth and crop yield, it causes each year on all crops probably, surpass the losses caused by any other single type of plant disease. Powdery mildews are biotrophic, highly specialized pathogens that attack nearly 10,000 species of vascular plants [5]. The fact that multiple powdery mildew species can parasitize a single host plant is a bit confusing. They have the potential to infect virtually any type of plant; however, various powdery mildews cause disease in different plants. These fungi may be restricted by plant family or may be restricted to a single host. Powdery mildew fungi (*Erysiphaceae*) are one of the most conspicuous groups of plant pathogens, comprising more than 500 species that attack more than 1500 plant genera [39].

Important crops, including wheat, barley, grapevines, apples, and several vegetables and ornamentals, grown in the fields and greenhouses are among the major targets of powdery mildew fungi [12]. Powdery mildew rarely kills its host but is responsible for the loss of water and nutrients and reduced growth and development. They can raise respiration and transpiration; reduce photosynthesis, and lower yields [36]. These factors can cause stress that can lead to the overall weakening of the host plant. Severe powdery mildew reduces seed quality and may discolor seeds and impair the flavor of the harvested product [35].

Powdery mildew decreases the aesthetics and ornamental value of infected plants by decreasing their growth, their flower and fruit quantity, and their leaf aesthetics, which in turn, can greatly decrease their salability. It is a widespread harmful plant disease that occurs in several economically important crops. Severe infections can lead to the death of the plant and can cost hundreds of millions of dollars to control [40]. Powdery mildew is so frequent, widespread, and ever-present among ornamentals and crop plants that the overall losses, in plant growth and crop yield, they cause annually on all crops probably exceed the losses caused by any other single kind of plant disease. These diseases are common in most fruit-growing areas of the world and under optimum conditions for disease development can result in massive yield losses. The severity of infection on any particular host plant varies between countries and within localities in the same country. Even though, the damage is different it reduces yields, sometimes as much as 20-40% [3].

3.5. Management of Powdery Mildew

3.5.1. Cultural Practices

Several cultural practices reduce or prevent powdery mildew. Good cultural practices go a long way in preventing and controlling powdery mildew. If the disease becomes problematic; avoid late-summer nitrogen fertilizer applications to prevent the development of succulent tissue, which is more prone to infection, avoid overhead watering to assist reduce the relative humidity, and remove and destroy all infected plant parts. For diseased vegetables and other annuals, eliminate as much of the plant and its debris as possible in the fall. This reduces the fungus's ability to survive the winter. Do not compost contaminated or infected plant debris. Remove fallen leaves that reduce overwintering inoculum, maintain appropriate fertilizer levels, and provide adequate water. Selectively pruning overcrowded plant material to help increase air circulation and enhance light penetration helps reduce relative humidity and infection [37]. Cultural practices that reduce humidity, such as pruning for improved air circulation and avoiding shady locations, also help to prevent powdery mildew [32]. The most adopted practice to escape from powdery mildew infection is to plant early in the growing season or use early maturing cultivars. Early-seeded crops and early-maturing cultivars are often less affected by this disease than late-harvested crops because the fungus has less time to spread and affect yield [41].

3.5.2. Biological Control

Several potential biological agents have been described for the management of powdery mildew. These include the hyper-parasitic fungus *Ampelomyces quisqualtis* which inhibits conidial preclusions and cleistothecia formation. Biological products need to be applied as protectants to be effective in controlling powdery mildew *Bacillus subtilis* and *Trichoderma harzianum* [27].

3.5.3. Host Plant Resistance

The best control for powdery mildew is to plant resistant varieties. This method is a safe and low-input way to manage plant diseases is to grow resistant varieties of a crop. Genetic resistance is very effective for managing powdery mildew [27]. Cultivars with resistance to powdery mildew are available for some ornamental species. Because chemical control for powdery mildew often involves season-long applications, the use of resistant cultivars is highly desirable [32]. A wide

variety of plants, including vegetables, roses, and Kentucky bluegrass, have varieties, that have been developed to be resistant or tolerant to powdery mildew. In cereals and several other annual crops, powdery mildew control is primarily through the use of resistant varieties [3]. Powdery mildews rarely kill plants but can be controlled by planting resistant varieties. Host plant resistance has been widely used in crop breeding to develop powdery mildew disease-resistant cultivars for avoiding or minimizing yield losses due to disease infestation [8].

3.5.4. Chemical Control

As a last option, after all, other remedies have been explored chemicals that are least toxic to people and natural predators, can be considered. Regular application of fungicides throughout the year when the plant is making rapid growth minimizes serious damage. Many fungicides have proven effective for the control of powdery mildew diseases. There are many chemical fungicides when employed singly or in combination, that can provide prevention or eradication of these fungi and are appropriate for commercial or home use. In severe cases, chemical control is done using sulfur and copper-based fungicides. Some fungicides that have a broad label for control of powdery mildew on many different ornamental species include propiconazole, potassium bicarbonate, and others [32]. An application of a fungicide might be required if cultural measures fail to prevent disease buildup or if the disease pressure is too high. The best results from chemicals come from a combination of cultural controls [37].

Several systemic fungicides are being used to control powdery mildews in cereals and other annual crops. Powdery mildew can be controlled by the application of sulfur, dinocap, benomyl, or certain other fungicides. Elemental sulfur also effectively controls powdery mildew in many crops. In tree crops such as apples, several sterol-inhibiting, systemic fungicides effectively control the disease. Sulfur may be used as a spray, like dust, and in the greenhouse as vapor. Dinocap, benomyl, and cycloheximide are used as sprays. Control of the powdery mildew disease is generally achieved through the use of fungicides, including sulfur and sterol biosynthesis inhibitors [42]. Elemental sulfur was one of the first fungicides introduced and it is still used to control commercially significant powdery mildew infections [43].

Chemical application for disease prevention and control has been employed for generations and many are safe and effective when used properly. For the management of powdery mildew diseases apply fungicides every 7-14 days to ensure continuous protection throughout the growing season. Under most conditions, weekly applications give adequate protection but during the rapid development of new growth, temperature fluctuations, and frequent rains, more frequent application may be necessary [36].

3.5.5. Integrated Disease Management

Integrated disease management (IDM) is a common-sense approach to disease control and plant care. It employs several measures to prevent, control, or reduce plant diseases. These include using resistant plant varieties, cultural practices, biological, and chemical controls. So by integrating these management methods, it can control powdery mildew diseases.

4. Conclusion

Fungi cause diseases in plants are a diverse group. Downy and powdery mildew are fungal pathogens that cause diseases in plants. They cause significant diseases on a range of crops and they are important plant pathogens, which are greatly responsible for the reduction of crop quality and yield worldwide. Downy mildew often causes rapid and severe losses of young crop plants still in the seedbed or the field, causing heavy or total losses of crop yields. Powdery mildew is also one of the most widespread and easily recognized plant diseases that affect economically important plants. The rapid identification of fungal diseases by timely recognition of their symptoms is an effective management practice and may help control and prevent their spread and progress. Applying cultural, chemical, biological, host plant resistance, and integrated disease management on time is important to reduce the damage caused by mildew diseases. Integrated disease management is the most appropriate method of managing diseases through combinations of various control measures and it might be feasible to control downy and powdery mildew fungal disease. Therefore, timely management of downy mildew and powdery mildew disease has an important mechanism to reduce pathogen effects and improve crop yields, and there should be needed research attention on the management methods.

Abbreviations

IDM	Integrated Disease Management
HPR	Host Plant Resistance

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Esuyawkal Demis: Conceptualization, visualization, writing-original draft preparation, and writing-review & editing.

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Conflicts of Interest

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