Chapter

Fungal Diseases of Wheat

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Abstract

Wheat is considered the first crop that is grown on earth. It is a staple food in many regions of the world. Due to the increase in the world's population, it is very important to increase wheat production. With an estimate in 2050, almost 50% more production of wheat will be required due to the increase in population. Increased productivity of wheat is the biggest challenge for researchers. It faces several biotic (microbial diseases) and abiotic (water, temperature, and climatic change) limiting factors. But the major threat for wheat is due to a large number of fungal diseased pathogens, which causes massive and destructive loss to the crop. It includes rusts, smuts, Fusarium head blight, Septoria leaf blotch, tan spot, and powdery mildew that cause the most serious losses. It was estimated in 2019 that almost 22% yield loss of wheat was due to diseases. These percentages will increase with time due to mutation and diversity in virulent strains. This chapter includes all major and minor fungal diseases of wheat, symptom, disease cycle, spore identification, disease losses, etiology, and integrated disease management.

Keywords: airborne, management, obligate parasites, root rot, seedborne

1. Introduction

Wheat (*Triticum aestivum*) is a grass commonly grown for its seeds, which are used as a staple food for many countries of the world. Wheat is a good source of carbohydrates and has low protein content. This low protein content help to supply important amino acids to the body. It is also a great source of many other nutrients and dietary fibers [1, 2]. Wheat is cultivated in almost all parts of the world with different ratios. In the world, annually, wheat is grown on an area of 5400 hundred thousand acres. The common forms of wheat that are used for eating are white and red wheat [3]. In the year 2017, 772 million tonnes of wheat were produced around the globe. Global wheat consumption is also increasing, it has gluten protein which helps in producing processed food. Processed food becoming an important part of the modern world [1]. China is the biggest producer of wheat with an annual production of 133.6 million tonnes in the year 2019 [4].

As the world population increases day by day it is estimated that agricultural commodities should be increased by 50% by 2050 to meet the demand and supply chain [5]. But major constrain in this race are abiotic and biotic factors, which affect the production every year. Abiotic factors are generated by the facilities of mankind that are climate change. While biotic factors include major disease pathogens, insects, pests, and weeds. These factors cause a reduction in the yield and quality of grain every year [6]. Serious biotic stress includes major fungal diseases, such as rusts, smuts, bunt, tan spot, fusarium head blight, foot rot, false eyespot, and many more. Three types of rusts and powdery mildews caused major disease epidemics in past and kept on threatening problems to wheat production besides, the development of various fungicidal chemicals and resistant cultivars. Cultivars become vulnerable to pathogens due to variation in pathogen virulence [7].

These effects can be managed by working on resistant cultivars, not against the diseases but also abiotic factors. Cultivars should be best fitted in the environment. Then proper nutrients should be provided to make the crop strong and protect the flag leaf of the plant. Agronomic practices should be done on time and a proper dose of fertilizer should be given to the soil. Explain new and environment-friendly approaches to the farmers to keep the wheat crop healthy and protected from major risks.

This chapter includes major and minor fungal diseases which attack the wheat crop, their mode of action, epidemiology, visual identification, and eradication methods.

2. Major fungal diseases

2.1 Obligate

2.1.1 Loose smut

Loose smut of wheat is a seed-born disease caused by *Ustilago tritici,* an obligate fungal pathogen belonging to division *Basidiomycota*, and the family *Ustilaginaceae*. This disease is reported everywhere, where wheat is cultivated. It was first reported by Romans and given the name *Ustilago* derived from the Latin word which means burn. Correct symptomology was given by Fabricius in 1774 in the book. In this disease, the plant is infected at the flowering stage and produces a sterile kernel-containing seed coat filled with smut spores. So, the disease is rarely spread by man. Its sores can easily spread to long distances with air and rain splashes. Loose smut of wheat was not reported in Australia, America, and South Africa, people from Europe move to these countries to settle down and bring wheat with them which was infected with loose smut. In North America, it was reported in 1832, although resistant genotypes were used against this disease but could not stop it from spreading. It is common in cold and humid regions but in dry areas causes equal yield losses. It does not cause huge economic losses but still, 2% disease in the field can cause yield reduction up to 20% plus make seeds not fit for next sowing. Loose smut is a seedborne pathogen; on maturity, the kernel is filled with dark brown to black color teliospores. The life cycle starts when teliospores enter the ovary through feathery stigma during anthesis [8]. Under favorable conditions when a single spike is infected with two different races, then, it is possible for recombination and genetic diversity. Mycelium survives inside the embryo without showing external symptoms. These spores will germinate when the infected seed is germinated. Pathogen spread systemically from one plant to another as well as inside the plant from cell to cell and reaches the tiller without producing any single external symptom [9]. The external symptom is very clear and easily recognized by black spores on a mature spike. This smut was released from the kernel as soon as the ear emerged out.

2.1.2 Wheat leaf rust or brown rust

Wheat is threatened with several diseases but rust is very dangerous for wheat. It causes huge economic losses all over the world. Wheat leaf rust is caused by *Puccinia* *triticina.* It was originated in the Middle East [10]. It is widely distributed where wheat is cultivated, therefore adopting a wide range of environments. Rust fungi are biotrophs and obligate parasites, they need living plants to complete their disease and life cycle. Rust fungi are host-specific. It can spread aeciospore, basidiospores, and urediniospores to far-off places by wind [11, 12]. This reason made it more diversified and the biggest reason for wheat economic losses; it adopted a wide range of environmental changes and increased inoculum amounts to cause disease epidemics [13]. It survives in mild temperature and higher moisture conditions. The disease reduces the size and weight of grain in the kernel. Leaf rust shows temporal and geographical variations and causes significant yield losses [14]. In the United States of America, during the years 2000–2004 leaf rust losses reached USD 350 million and in Australia up to AUD 12 million [14, 15].

Puccinia triticina is a macro-cyclic and heteroecious fungus. It requires two different hosts to complete its sexual and asexual life cycle. Its life cycle consists of five different spore stages. When environmental conditions are suitable fungus produce dark brown teliospores, which are diploid and on germination undergo meiosis and produce haploid basidiospores on the surface of a leaf. These basidiospores move by the wind too far-off places and require an alternate host to produce haploid pycnial on germination [10]. Alternate host of *Puccinia triticina* includes Anchusa, Isopyrum, Thalictrum, Barberry, and Clematis. After infection on alternate host rust produce pycniospores disseminate by insects, undergo sexual propagation into two, unlike cells which form plasmogamy. Aeciospores are produced in aecia and liberated by the wind. The life cycle ends when aeciospores germinate into asexual urediniospores and produce visual symptoms on the host plant. External symptoms include pustules circle or slightly oval but smaller than stem rust, these pustules do not merge in each other (**Figure 1A**). These pustules are filled with orange to the brown mass of urediniospores. Infection occurs on the upper side of the leaf surface. All these five types of

Figure 1.
Brown rust of wheat (A), black rust of wheat (B), and stripe rust of wheat (C).

spores are produced either by sexual or asexual reproduction. Asexual reproduction is carried out by urediniospores, which undergo many stages and form haustoria which are used to obtain nutrients from the host plant. It also suppresses the plant defense system and helps in fungal growth and germination [16].

Optimum temperature ranges between 10 and 25°C and free moisture for long period on the leaf surface help in disease infection. If favorable conditions prevail then the uredinial cycle repeats after every 8–14 days. Urediniospores, teliospores, and basidiospores are produced on wheat while pycniospores and aeciospores are produced on the alternate host. Teliospores are produced at the end of the season; so, it helps in overwintering and becomes a source of inoculum for the next growing season. Due to the monocyclic nature of the fungus they produce spores end of season and act as primary inoculum, these spores germinate on wheat individually and cause infection. P. *triticina* produces pustules of 1.5 mm in diameter which contain 20 k spores during advanced growth stages.

2.1.3 Wheat stem rust or black rust

Stem rust of wheat is historically a major disease of wheat caused by *Puccinia graminis* f. sp. *tritici*. It is also known as the black rust of wheat. Due to its historical yield losses of wheat, it comes in the top 10 fungal diseases which can cause devastating losses to crops [17]. It causes severe yield losses up to 50% region wise. On severe attack yield losses reaching up to 90% [18]. It causes yield losses in Canada, South America, Africa, Australia, China, and Indian Subcontinent [19]. Stem rust was a devastating disease for wheat and other cereals for many years. After applying so many management applications, it was eradicated but stem rust re-emerged in Africa and Europe and became a risk for food security. Severe disease attacks occur when a pathogen changes its virulent strain like UG-99 and TKTTF causing 100% yield in Uganda and Ethiopia, respectively [19]. Stem rust destroyed wheat in the United States up to 20% many times during the early 1900s [20]. Airborne pathogens can move from infected fields to healthy in no time, and this connected world increases the chances of spreading too many times. Small size urediniospores can move from one continent to another very smoothly. Like UG-99 moved from Uganda to South Africa, Iran, Russia, and TKTTF moved from Ethiopia to Germany, the UK, Sicily, Sweden, and Denmark [21]. Annually, stem rust causes a loss of 8–54 billion dollars every year globally [22]. Stem rust pathogen is an obligate parasite with a biotrophic mode of nutrition, so, it requires more living hosts to complete its life cycle. Pathogen belongs to phylum *Basidiomycota*, it is different from other fungi because it also produces five different spores to complete its life cycle like leaf rust as discussed earlier. It is also heteroecious, requires two hosts to complete its life cycle. Its primary host is wheat and the alternate host is the barberry plant. However, *Puccinia graminis* can complete its life cycle with or without an alternate host.

After 1–2 weeks of disease, infection urediniospores are produced in uredinia. It is the repeating stage in the whole life cycle. Urediniospores are dikaryotic produced on the separate stalk in the fruiting body. These spores can infect the host plant and produce external symptoms (**Figure 1B**). It produces red rusty spores which become dark, this is the reason it is also known as black rust [23]. When the growing season of crop ends it produces teliospores in telia. Teliospores are also dikaryotic and overwinter in the absence of the host. When teliospores get favorable conditions, they undergo meiosis and produce haploid basidiospores, these are colorless spores capable to infect alternate hosts but not cereal hosts. After germination, it produces pycnidiospore, which produces sticky honeydew which attracts insects and becomes a mode of perpetuation. Pycnidiospores mat and produce dikaryotic aeciospores in aecia. These aeciospores germinate and produce urediniospores but on cereal host not on the alternate host. Urediniospores may pass from winter wheat to spring wheat without infecting the alternate host. The optimum temperature is 30°C and 2 hours of leaf wetness can cause infection [18].

Puccinia graminis goes through meiosis so chances of recombination are many more. The number of strains reported includes UG-99, JRCQC, MCC, QCC, QCCJ, QCCJB, QCCS, QFCS, and TPMK. These all strains were reported at different times from different regions of the world [24, 25].

2.1.4 Stripe rust or yellow rust

All rust species are very destructive but stripe rust is most of all. It is caused by *Puccinia striiformis* f. sp. *tritici*. It belongs to the phylum *Basidiomycota*, and it is also heteroecious. It has a wide range of host plants. It can infect wheat, rye, barley, and other grass species. It can cause 100% yield loss if variety is susceptible and environmental conditions are favorable, but the losses varied between 10 and70% which mainly depends on epidemiology, area, variety under cultivation, and race of pathogen [26]. It was first reported in Sweden in 1794. It is present almost around the globe except in Antarctica. Its losses reached 46% in Asia which makes it a major limiting factor for the wheat crop [27]. The severe outbreak occurred in Turkey, Iran, and Uzbekistan, likewise in 2009-10 diseases occurred in epidemic form in western and central Asia and the North part of Africa [28]. Stripe rust is spreading very fast and changes the strain immediately, so, it is not easy to produce resistant genotype against stripe rust. It causes a wheat loss of 5 million tonnes which is worth equal to 10 million USD annually. It spreads into dry and warmer places as well and due to change in the cropping system and shifting of time of sowing make it more powerful [29].

Disease infection occurs anytime throughout the growing season. It causes symptoms on the green part of the plant which includes leaf, leaf sheath, glumes, and awn (**Figure 1C**). The disease infection cycle is similar to other rust pathogens. Infection caused by urediniospores and optimum temperature for disease infection is 3–20°C and free leaf moisture for 3 hours. The optimum temperature for infection on barberry is 10°C with 32 hours of leaf wetness [30]. When the temperature goes higher urediniospores change into teliospores. If the temperature goes down from −9°C, it completely stops the spores from germination. These two spore phases take place on wheat host remaining carried out on alternate host. *P. striiformis* spores can move by wind and it is assumed that they may travel from Armenia, Georgia, Azerbaijan, Turkey, and then move to Europe [31]. It was reported firstly at higher altitudes with cold weather but now it undergoes environmental adaptations and is reported in Asian countries as well [32]. Weather conditions are very important for disease infection, pathogen viability, growth, and sexual and asexual reproductions, all are linked with weather conditions plus vulnerability of wheat and alternate host [31]. If teliospores germinate at right time on an alternate host, it will complete the infection cycle of *P. striiformis.*

2.1.5 Powdery mildew

After rust and smuts mildew is a more contagious disease for plants. In wheat, powdery mildew is caused by *Blumeria graminis* f. sp. *tritici*. It is an obligate parasite but not heteroecious like a rust pathogen. It is considered as 6th out of 10 fungal yields threatening disease and 8th at the major disease in the world [17]. Powdery mildew is a very important disease in temperate and nautical climates in regions, such as America, Africa, and Europe. It occurred in epidemic form in China in 1980 and caused huge crop yield loss. In the year 2006–2008, it attacked an estimated around 7 million hectares area. It caused yield loss ranging between 5 and 35% [33]. It is an endemic disease and disseminates in different countries of the world. Yield losses up to 22.5% in Egypt on susceptible cultivars [34]. It causes 35% of disease losses in Russia and 62% in Brazil [35]. The pathogen attacks the plant at the lush green vegetative stage, mostly high-yielding genotype and high-nitrogen fertilizer making a plant vulnerable to powdery mildew. Ascospores or conidia germinate and enter the leaf surface to produce hypha with appressoria in 2 hours, this hypha changes into penetration peg, and haustorium allows to enter cell epidermis [36]. Infection reduces photosynthetic rate, leaf assimilation index, and increases the rate of respiration which ultimately affects the quality of grains. It affects plant vigor, tillering, heading, and grain-filling stages. Plant heavily infected gets died completely. When the wheat plant gets infected with powdery mildew at the tillering stage, it affects the booting stage which directly influences yield. It reduces grain size and weight of grain which causes a 40% reduction in crop yield if flag leaf gets infection then losses are much greater [37].

External symptoms include a grayish powdery colony on the leaf and stem of the wheat plant. It is most prevalent on the upper and lower surfaces of the leaf (**Figure 2**). The powder appears in the form of white patches early in the season, but disease duration can be prolonged if favorable conditions prevail. These white cottony pustules produce asexual spores known as conidia which are later on spread by wind. Sexual spores are ascospores that developed in cleistothecia. Both sexual and asexual spores are born in humid weather with a lower temperature range.

On disease progress, it covers the entire plant and turns into yellow color due to chlorosis, black color fruiting bodies appear on a leaf along with the gray powdery mass. Fungus mass can cover the head-on severe attack. The temperature range between 10 and 21°C favors the disease. Infection is reduced at the flowering stage as the temperature rises, so, fungal grow inside the tissues during winter times. When the temperature becomes suitable, it starts germination and spreads from plant to plant and field to field by wind. High humidity and temperature range between 15 and 20°C are most suitable for disease spread, repetition of the life cycle in 7–10 days, and development of new strains [38].

Figure 2.
Visual symptoms of powdery mildew on the wheat leaf (A) and spikes (B).

2.1.6 Karnal bunt

Karnal bunt of wheat is a very common disease everywhere, it is caused by *Tilletia indica* (**Figure 3**). It was first time discovered in India in 1930 [39]. Afterward reported in Iraq, Pakistan, Nepal, Afghanistan, USA, South Africa, and Mexico [40]. Karnal bunt of wheat is an air, seed, and soilborne disease, and spread easily to far-off places. It affects the quality of seeds as well as makes them unfit for eating and sowing. The disease produces a specific smell even 1% contamination occurs. It was assessed that if wheat grains are infected with 3%, it is not suitable for human consumption. Infected seeds also become less fertile [41]. The disease can cause huge yield losses, in India, yield losses due to Karnal bunt up to 40% in severely infected fields; in the year 2014–2015, disease incidence was 15% reported in India [42, 43]. Due to its massive yield losses and easy perpetuation, many countries banned importing wheat from those countries where this disease was common. Almost 30 different countries adopt zero-tolerance quarantine measures to avoid disease and its after-effects. Karnal bunt causes 7 billion US dollars loss in Mexico every year [43]. Disease epidemics mainly depend upon weather conditions, when the temperature and humidity are suitable disease infection occurs on wheat. Teliospores germinate when the temperature is 20–25°C, if 20°C temperature, pH 6–9.5, and moisture for 3 weeks disease outbreak occurs. Teliospores need an 80% moisture rate or free water for germination [40].

Clear symptoms can be seen after threshing as grain in the spike are swollen and fell off with the wind. Spike length and number of spikes per plant also reduce with the disease (**Figure 3B**). It is also found that all ears in the spike are not bunted, however, infected grains are converted into bunt sori (**Figure 3A**). Sori is oval-shaped contains black to brown powdery spores enclosed in the pericarp (**Figure 3C**). In a severely attacked spike, the lining of the seed coat and epidermis is destroyed and spores are enclosed in the lining of the pericarp [40]. This smut fungus has a different pathogenesis method, the fungus infects wheat after diazotization and starts germination and colonization in the epidermis of the plant and infection spreads from cell to cell [44]. Teliospores germinate diploid nuclei which undergo meiosis and several mitoses and produce haploid basidium. Haploid nuclei develop and produce basidiospores. One

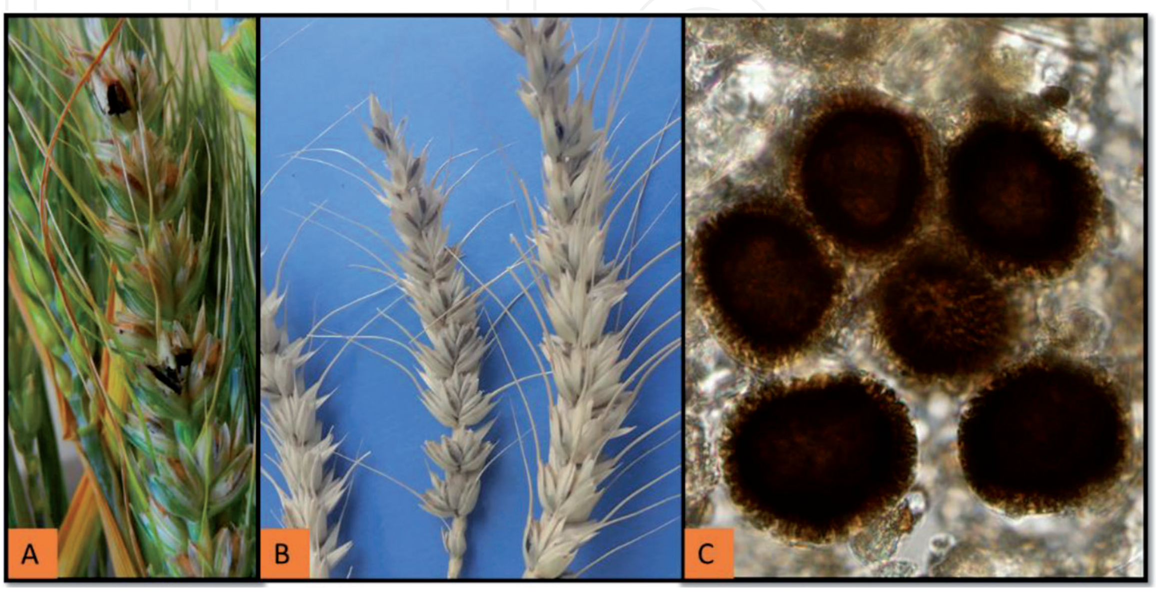

Figure 3.
Karnal bunt in wheat spike (A, B) and dark brown teliospores from bunt sori (C).

daughter cell back to basidium and produce 110–185 sporidia on the tip and are sickle-shaped. With rain splashes and wind, teliospores drop on soil and become a source of primary inoculum, it can survive in the soil for many years [45]. Secondary sporidia (allantoid and filiform) are more durable and germinate when getting favorable conditions and play important role in the disease cycle. Allantoid plays role in infection and filiform increases the number of inoculum in the soil. Sporidia are binucleated and on germination produce a germ tube that penetrates newly developing seed in the ovary. Bunt fungus causes infection at the time of anthesis [46]. The disease produces a characteristic fishy smell as teliospores that release trimethylamine [40]. If the conditions are not favorable or the wheat plant does not reach the vulnerable stage when teliospores germinate, it leads to "suicidal germination." [47].

Spores of Karnal bunt can survive in the soil for 3 years, it can spread from one farm to another through farm machinery. It can tolerate very cold temperatures and maintain its viability. Air can spread spores up to 3000 meters [48]. Teliospores are resistant to chloropicrin, hydrogen peroxide, methyl bromide, ozone, and propionic acid [47]. Single pathogen isolates can vary from one another by physical and morphological characteristics, the number of chromosomes, degree of infection

Figure 4.
Flag smut of wheat.

production, and resistance to host barriers. *T. indica* is the most effective and over-breaking smut fungal pathogen from all of the others [40].

2.1.7 Flag smut

Like loose smut, flag smut is also a very important disease; it is caused by *Urocystis agropyri* (**Figure 4**). It is an obligate pathogen like all other rusts and smuts pathogens, it needs a living host to complete its life cycle. Symptoms include twisting and bending of infected seedlings, white patched areas appear with blistered and develop coleoptiles. On the mature plant, symptoms appear on leaves with white areas which turn gray to black afterward. Stunted growth, distorted and twisted tillers may not produce spikes and grains. Poor root development was also observed in the infected plant. If grains produced are also infected and show poor germination if cultivated again. Losses due to flag smut varied between 5 and 20% depending upon the availability of environmental conditions [49].

2.1.8 Common bunt

Common bunt of wheat is caused by *Tilletia caries,* it is the most destructive disease of wheat. It occurs at the grain-filling stage, with spikes filled with bunt spores instead of grains. Spores produce a smell resembled with fish. Spores are airborne and bunt stuck with healthy grains during harvesting and become a source of infection for the next year. These infected seeds spread all around in trading and exportation. Common symptoms appear on spikes that are darker in color as compared to healthy spikes, on maturity these infected spikes turn bluish-gray [50].

3. Non-obligate

3.1 Fusarium head blight

Fusarium head blight [FHB] also known as ear blight and the head scab is caused by different fungal pathogens, including *F. culmorum, F. graminerarum*, and *F. avenaceum.* The most common pathogen is *F. graminearum,* which is found in America, Europe, and Asia [51]. It prevails in crop residues in the form of saproprobes; inoculum consists of conidia and ascospores; ascospores are sexual spores produced in perithecia fruiting body and released by wind [52]. Conidia are asexual spores and produce mycelia which infect plant leaves and spikes. *F. graminearum* produces many mycotoxins, such as nivalenone, zearalenone, deoxynivalenol, and moniliformin, which causes significant food poison for humans and animals [53].

Wheat plant is susceptible to FHB from the anthesis stage till kernel production. Main external symptoms appear on the head, peduncle, spikes, and grains. Yellowing to slight discoloration of infected spikelet starts while healthy spikes are green (**Figure 5**). Infected spikes contain pinkish and orange shade colonies of spores. Spores are produced in cold and humid weather. Infected seed is cultivated in the next season results in red to brown shade colony with poor tiller came out. Reduced size and less vigor and well as affect germination rate of seed. Other morphological characters include the late heading and tiller stage [54]. Its symptoms are mostly confused with root rot and crown rot disease, and incomplete symptoms are confused with glume blotch and black chaff.

Figure 5.
Fusarium graminearum *symptoms on infected wheat nodes and spike.*

Optimum conditions for disease infection are moderate rainfall, and temperature range between 24 and 29°C for 2–3 days is enough for infection. Fungal spores survive in crop residues. High humidity and rainfall not only increase inoculum but also help in dispersal.

3.2 Tan spots

The tan spot of wheat also known as yellow spot or blotch is caused by *Pyrenophora tritici repentis.* Tan spot is very common in the UK, Sweden, Germany, France, and Denmark; this causes serious wheat yield loss.

It has a wild range of host plants, including grass species. Most of them are perennial crops that help in overwintering pathogens and increasing the number of inoculum for disease epidemics. It causes 5–10% yield loss and when environmental conditions are favorable losses reached 50% [49]. Symptoms include small dark brown fleck which turns black spot on basil leaves. Then spots merge and get enlarged into tan and irregular lesions with browning inside and yellow rings surround the lesion. Under humid conditions, lesions produce dark spores, and lesions combine and produce dead tissues. Infected seeds contain pink to red color spores, black points, and low germination.

Fungal survive in the form of dormant mycelium on crop residues. Pseudothecium is the fruiting body and ascospores are produced inside. Ascospores spread with the wind too far-off places, infected seed is also a source of disease spread. Under warm and wet conditions, asexual conidia germinate and spread with rain, it infects the ear, glume, and developing grain. Optimum temperature ranges between 20 and 28°C and disease symptoms appear in 7–14 days [49].

3.3 Septoria disease

Septoria is a disease complex caused by three different pathogens called *P. avenaria triticae, Mycosphaerella graminicola,* and *Phaeosphaeria nodorum.* While diseased caused by *Mycosphaerella graminicola* (anamorph; *Zymoseptoria tritici*) is called Septoria tritici blotch [STB]. This pathogen not only reduces the size but also the quality of grain. When disease occurs in the epidemic form, it causes 30–50% yield losses. It occurs in strong epidemic form in those areas where the temperature is lower and wet humid weather. It is most common in North and South America, North and South Africa, the north part of Europe, and Turkey [55]. External symptoms include chlorotic lesions on leaves appearing in fall and spring, with the disease advancement it becomes darker and produces fruiting bodies on the lesion (**Figure 6**). It produces pseudothecia as a sexual fruiting body and pycnidia as an asexual fruiting body.

The infection starts when airborne ascospores germinate on the plant which is overwintered in plant residues. Infection occurs just after the emergence of seeding. Sexual spores attach with stomatal opening with the help of germ tube and enter into the stomata and produce appressorium. After 7 days, it produces hyphae and mycelium inside the whole plant. The pathogen has both biotrophic and necrotrophic mode or growth when it changes its mode then external lesions appear on leaf and cell collapse. On disease, advancement lesions change from light to dark color. Conidia are produced on the necrotic site which spread with rainwater from infected to healthy plants as well as over winter in residues and become a source of inoculum for the next crop. Pycnidia produce conidia within 15–40 days after infection, it depends upon environmental conditions. Under unfavorable conditions, spores undergo a dormant state and germinate when the temperature and moisture are available [56].

3.4 Common root rot, crown root rot, and black point

The number of diseases caused by *Bipolaris sorokiniana* in different cereal crops causes crown root rot, common root rot, and black point disease in wheat leads to huge yield losses [57]. Root rot occurs everywhere in wheat-cultivated areas. Canada lost 5.7% of wheat due to common root rot which was worth 42 million dollars. Crown root rot is very common in the pacific region. It causes 35% yield losses over there [58]. When seeds are infected with *Bipolaris sorokiniana* causes black points on the wheat plant which on advancement results in rotting and blight disease of seedlings. Black point disease appeared as brown to blackish tips on the embryo of grains, it increased the weight of kernel but grain quality reduced. These infected seeds if cultivated for the next season it will reduce seed germination, increase seedling

Figure 6.
Septoria leaf blotch symptoms on the wheat leaf (A) and sclerotia on the stem and leaf (B).

Figure 7.
Rhizoctonia root rot (A) and fusarium head blight (B).

death, reduce seedling emergence, and reduce photosynthetic rate ultimately affecting normal growth [59]. It is also observed that disease is associated with *Alternaria, Penicillium, and Fusarium spp.* and caused huge losses [60]. The disease causes losses up to 90% if favorable conditions prevail for a longer time. The favorable temperature ranges between 28 and 30°C and relative humidity requires up to 90% [59]. Fungus goes through teleomorph known as *Cochliobolus sativus*, it is the sexual stage and reported first time in Zambia, while sexual reproduction of *C. sativus* has not been reported everywhere. *B. sorokiniana* reproduce asexually through conidia [58]. Common root rot and crown root rot cause significant losses in China, India, Australia, and Europe. Symptoms include necrotic lesions on roots and with the disease advancement lesions become darker [61]. It is very common in dry and warm regions of the world. Disease incidence is affected by soil temperature and moisture, severity increases when the plant is under stress conditions.

Root rot is one of the serious diseases for wheat, especially in Egypt. It can cause significant yield losses because it attacks the seedlings just after germination from the seed. The disease is caused by *Rhizoctonia solani* and *Fusarium graminearum* (**Figure 7**). In combination, these two pathogens are very severe. Fusarium cause wilting and R. solani causes damping-off. Fungal pathogens germinate, colonize, and enter the roots; they block the roots by growing mycelium inside the root. Plant or young seedlings are unable to get nutrition and ultimately die off [62, 63].

4. Minor limiting factors

Wheat is also affected by some minor diseases which are sometimes causing huge crop yields. It includes different types of viruses, bacteria, and nematodes. Wheat is affected by the number of soilborne viruses named as *soilborne wheat mosaic virus* belongs to genus brymovirus. This genus has other members, such as *wheat yellow mosaic virus* and *wheat spindle streak mosaic virus. The soilborne wheat mosaic virus* causes heavy losses in USA and Brazil in the early 90s, 50 and 80% respectively.

Symptoms included were a yellow mosaic appearance on leaves and stunted growth with a poor root system.

Wheat spindle streak mosaic virus causes 30% yield losses to wheat sown in winter. It shows chlorotic as well as necrotic streaks along with leaf veins. It reduces crop height and seed production [64, 65]. Nematodes include cyst nematodes in which 2nd stage juveniles enter the root and move toward the vascular system. Nematode enlarges its size and develops syncytia which withdraw food and nutrition from nearby cells. This serves as an endoparasite. Adult females lay eggs within 3 to 6 weeks of infection and cover these eggs to protect them from unfavorable conditions. Wheat is also infected with *H. avanae*. Another nematode *Anguina tritici* causes seed gall disease in wheat and other important cereals.

5. Management

Wheat is important and staple food all over the world. The main source of carbohydrates and used in a different form. But its production is affected by the number of diseases. Wheat is affected by several fungal diseases. The major threat to wheat is due to rusts, smuts, and mildews. Crop rotation, soil solarization, and zero tillage are important tools for disease management. The use of a resistance cultivar against different pathogens is an effective strategy. Resistant cultivars, certified pure seeds, and seed treatment with strong fungicide are effective to control for these rust and smut diseases [66]. Breeding for resistant varieties to manage loose smut, inheritance of resistance in hexaploid wheat cultivars is examined [67]. Back cross of seven resistant and two susceptible varieties against loose smut disease artificially inoculated in mid of anthesis stage. The segregation ratio showed that resistance against loose smut is controlled by a single dominant gene in wheat [68]. Another study reviled that resistant genes against loose smut are partial and complete resistance which are both dormant and recessive, these resistance genes can stop or hinder the growth of smut inside the plant at different points [68].

One of the powerful and effective tools against disease resistance is host-induced gene silencing in the transgenic plant. It is also helpful in functioning and gene characterization. New and advanced techniques help in contrition of efficient transgenic system and enhance RNAi-driven strategy against the resistant plant. These new and advanced techniques are proven best against biotic and abiotic stresses and another best part of these techniques, they are environmentally friendly and farmer friendly. Genome editing by Cas-9 is very important and helpful in the insertion of resistant genes against pathogens to produce resistant cultivars [69, 70].

The use of biological control agents against pathogens is effective and widely used technique because of the chemical resistance problem. The use of *B. megaterium, T. harzianum, B. amyloliquefaceiens,* and *Epicoccum spp. is* proven effective against different root rots [71]. The use of *T. harzianum* and *T. koningii* are significant against *B. sorokiniana* and *A. alternata* [72]. *Trichoderma spp.* and *Bacillus* give significant inhibition against different root rot pathogens [73].

Chemical fungicides are used for seed treatment and foliar application. Use of Carbendazim, carboxin, triticonazole, thiram, metalaxyl, as a seed treatment for seedborne diseases in wheat [72]. Tubeconazole in combination with imidacloprid and cyproconazole along with difenoconazole are effective chemical fungicides against rust and smut diseases of wheat [74]. Seed treatment with difenoconazole, fludioxonil, homai, and vitavax is proven best against seedborne pathogens.

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